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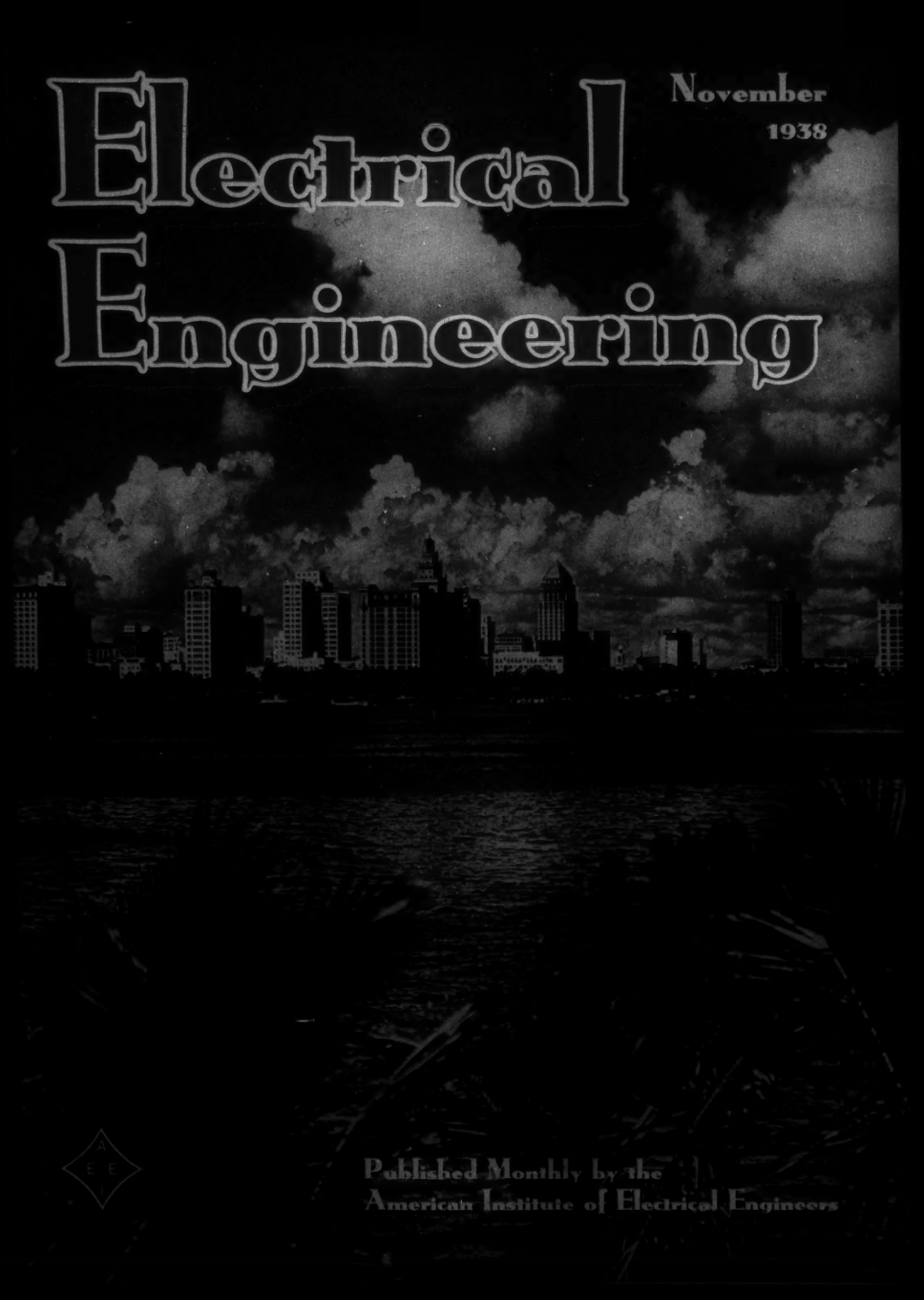

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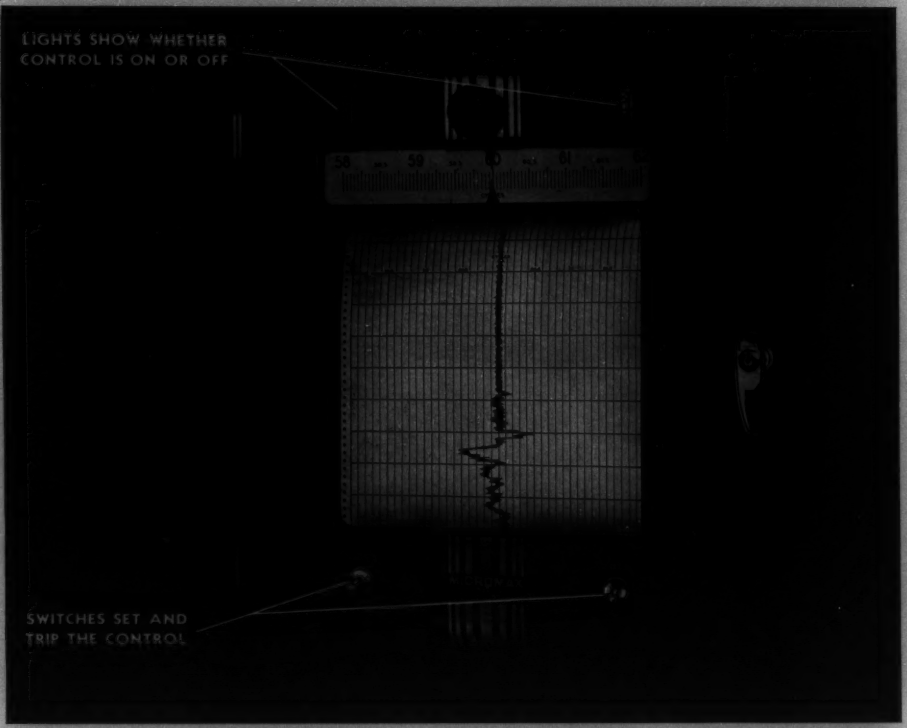

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for November 1938—

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The Cover

Miami, Fla., scene of Southern District meeting November 28–30, across Biscayne Bay

Photo by G. W. Romer

High Lights

Circuit Breakers. Compact design of an air circuit breaker may be obtained by forcing the arc caused by the operation of the breaker into a series of arc spaces, where the rapid development of a thin layer of dielectric material at the cathode interrupts each individual arc. Such breakers may be used on voltages up to 25 kv (*Transactions pages 649–57*). By modifications in design, a new air circuit breaker, providing protection against fault currents up to 20,000 amperes at 250 volts on direct current or 600 volts on alternating current, has been produced (*Transactions pages 657–61*).

Constant-Current Circuit. A constant-current circuit without moving parts may be constructed by connecting an iron-cored reactor with predetermined characteristics in parallel with a capacitor of such size that the resultant input current is independent of line voltage. The parallel circuit is connected in series with the element through which the current is to be regulated (*Transactions pages 636–9*).

Position Regulator. Among other industrial applications for photoelectric tubes are many devices used for simplifying or improving the accuracy of operation in the manufacture of paper. A recent comer to this family of devices is a position regulator, used for the accurate trimming of paper webs, so that a roll of paper with even sides may be wound from an unevenly wound roll (*Transactions pages 634–6*).

Noise Co-ordination. Investigation has shown that satisfactory co-ordination of power and telephone facilities in rural areas for the reduction of noise in the telephone circuits can be secured by control of the influence and susceptiveness of the circuits. One of the measures that may be applied to the power system is the use of shunt capacitors to improve the wave shape (*Transactions pages 613–21*).

Electric Strain Gauge. An offspring of a vibration recorder originally described in 1926, the electric strain gauge measures mechanical strain electrically, and has been valuable in the study of stresses in railroad tracks and bridge members. As described in this issue, it is equally successful in measuring the strain in machine parts subjected to stress (*Transactions pages 645–8*).

Radio Noise. Electrical apparatus may cause noise in radio receivers of such magnitude as to impair reception in some circumstances. A method of measuring the radio-influence characteristics of apparatus was recommended by a joint committee, and laboratory experience now shows that the method is practicable and gives results that are reproducible by quantitative measurements (*Transactions pages 626–33*).

Wound-Core Transformers. For years the most satisfactory type of transformer core has been made from sheets or punchings of sheet steel assembled about the windings in such a way as to require little power for supplying eddy-current losses and magnetizing current. Now a low-loss transformer may be assembled by winding the core around the finished coils by machine (*Transactions pages 622–6*).

Harmonic Generators. Experience usually is the only guide in designing and adjusting harmonic generators, such as those used in radio transmitters. In this issue a new method of analyzing the harmonic generator is presented. It requires very little tedious computation, and is sufficiently accurate for practical design (*Transactions pages 640–5*).

Lightning-Arrester Performance. Continuing a previous report on the performance characteristics of lightning arresters of the line type, the lightning arrester subcommittee of the AIEE committee on protective devices presents in this issue a report of the characteristics of arresters rated at from 20 to 73 kv (*Transactions pages 661–2*).

Range Utensils. Electric range units are of various types, heat being transferred from the unit to the contents of a utensil by conduction and radiation in proportions according to the type of unit. Efficiency of heat transfer is affected greatly by the kind of utensil, some combinations of units and utensils differing in over-all efficiency by as much as 24 per cent (*pages 449–52*).

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Paradox. On the basis that the very improvement of production that might save us from economic and social collapse might increase rapidly the complexity of social organization and hence lead to the same collapse, an engineering educator proposes "planned education" in order that new professional generations may learn how to cope with these increasing difficulties (*pages 444–8*).

Training Graduates. Engineering graduates have shown themselves to be the best material for filling technical and administrative positions of responsibility in industry; proper training by industry is necessary to qualify them as executives capable of solving the perplexing problems of modern business (*pages 441–4*).

Southern District Meeting. A well-rounded program has been planned for the AIEE Southern District meeting, to be held November 28–30, 1938, in Miami, Fla. Besides carefully planned technical sessions, many interesting sight-seeing trips and other diversions are to be provided (*pages 460–61*).

Graphics. Solving equations containing complex quantities usually is a laborious task, especially by means of the conventional analytic methods. A graphic method for simplifying the usual manipulations of complex quantities is presented in this issue (*pages 453–4*).

Ultraviolet Sterilization. Radiation in the ultraviolet region at wave lengths of some 2,600 Angstroms has been known to kill bacteria and microorganisms, but only recently has a device or "lamp" been developed to produce this radiation conveniently (*pages 455–9*).

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: an article on engineering and the law by C. W. Appleton; an article on high-voltage dielectrics from the chemical standpoint by F. M. Clark (A'24); an article on glass insulation by R. E. Ferris and G. L. Moses; an article on lightning studies by K. B. McEachron (F'37); a paper on positive-grid characteristics of triodes by R. W. Porter (A'38); a paper on remote control of network protectors by W. R. Brownlee (M'38) and W. E. Dent, Jr. (A'38); a paper describing a new multibreak interrupter for circuit breakers by R. M. Spurck (F'37) and H. E. Strang (A'28) and a paper describing tests on such a breaker by Philip Sporn (F'30) and H. P. St. Clair (M'29); a paper on system analysis for application of Petersen coils by W. C. Champe (M'35) and F. Von Voigtlander (A'29); and a paper on the fundamental principles of fluorescence by G. R. Fonda.

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

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Training Engineering Graduates in Industry

By L. W. W. MORROW
FELLOW AIEE

Industry must train men to fill technical and administrative positions in a business world that becomes increasingly complex with economic, social, and legal aspects. Engineering graduates have shown definite advantages over nonengineering graduates for all types of positions; industry's objective is to get the best possible men and to train them with diligence.

INDUSTRY develops its younger personnel to take positions of technical and administrative responsibility. Industry needs a constant influx of men to carry on its expansion programs, to replace inefficient men and those who retire, and to keep itself competitive by the introduction of employees with new ideas and fresh initiative.

It may be taken for granted that industry seeks men with certain general characteristics. They should be of good mental and social habits with quick and intelligent responses. They should be responsible and decisive, yet have the ability and tact to get along with other employees. They should have the spirit and unselfishness to build the organization as well as to try to establish their own position.

When industry looks over its records to find the type of man to train, the answer is unmistakenly the young college graduate in engineering. These men have proved versatile enough to fill all technical and administrative positions. They may not be perfect, but experience indicates that they are the best available.

A sample of their accomplishments is given by the recent study made by President Karl T. Compton of Massachusetts Institute of Technology. Data on 54,000 officers of some 500 typical industries showed that the college man is 7 times more likely to be an official than the noncollege man, and that the engineering graduate is 30 times more likely to be an officer than the graduate of a nonengineering college.

This advantage of the engineering graduate over the nonengineering graduate applies to all positions. He has 12 times the chance to become president, 5 times the chance to be a treasurer, 30 times the chance to hold positions in production, 174 times the chance in engineering, and 24 times the chance in sales.

These data should be a source of stimulation and gratification to both engineering educators and the engineering profession. Moreover, they prove to industry that engineering graduates should be hired and trained.

Industrial executives accept the fact that any type of raw material in man power will develop on an individualistic basis independently of the individual's training and education, because there is little uniformity in a group of human beings. Each recruit is innately endowed with his distinctive traits and abilities. The greater is the credit, therefore, to the educators and to the formal and informal selective process applied to those who take engineering courses, to find that the engineering graduates stand out as the most competent men available for hire.

The time has passed wherein industry hires young engineering graduates to fill its demands for technical engineering positions only. In large measure this fact is not recognized by engineering educators or by the young engineering graduates. Experience with young engineers causes industry to hire them to fit into all the functional positions of a business and the training process is depended upon to cull out from the group the relatively few technical men required. For one position in engineering there are a dozen in other divisions of activity and these positions seldom call upon their incumbents to use any depth of technical knowledge. Yet the engineering graduate can and does meet the specifications for these positions to best advantage.

Perhaps this comes about because of the "method of attack" alleged to be peculiar to engineering training, but it is more logical to assume that the young engineer has more familiarity with engineering processes, industrial equipment, and the underlying sciences than other college men, and thus has less fear and less unknown territory to explore in order to become useful in industries which now combine large amounts of power and complicated assemblies of machines. Engineering knowledge, however superficial, gives the young engineer confidence and a feeling that he can act and think intelligently in the industrial environment.

Essential procedure by industry in dealing with a group of young engineers can be stated briefly:

1. To find individual aptitudes, habits, and personal traits.
2. To place individuals where their talents and personal characteristics can be used to best advantage.
3. To train each man constantly in order to bring out and develop his good qualities and to eliminate or reduce those habits and characteristics that handicap him.

Whether organized as a formal training course or not, no industry invests in young engineering graduates without trying to carry out such plans for their training and selection.

Two Stages of Development

An industrial manager takes the position that each engineering graduate starts with a small capital of knowledge, experience, and personality and semifixed attitudes and

An address presented at the 18th industrial conference, Pennsylvania State College, State College, April 12, 1938.

L. W. W. MORROW is general manager of the fiber products division of the Corning Glass Works, Corning, N. Y. A biographical sketch of Mr. Morrow appeared in the October 1938 issue, page 434.

habits. For some years he is placed in an environment that permits him to add to these assets without expectation of concurrent profit to himself or to his employer. Until he reaches some measure of equilibrium between his resources and the needs of industry, he is forced to use pressure to apply his talents to the utmost in order to advance his personal position. This is almost a planned program and attitude adopted by the employer and the employee.

As the engineer grows older and learns more, his functions increase and his perspective should change from that of self-interest to that of more unselfish interest in the organization. He must change from the attitude of a follower to that of a leader. Instead of performing himself he must get others to perform. He must select men, train them, and stimulate them to think in terms of the organization. He must learn to co-ordinate the work of subordinates, to check performance, and to appraise and reward good work. To the industrial executive this second stage proves whether the man is worth-while. In this second stage the young engineer is expected to give attention to many things outside the normal routine of his personal responsibility in the business enterprise. He should concern himself with the relations of his company to society, to government, to other business, and to employees as a group. He should learn how best to measure the future and become sufficiently objective to speculate as to trends and new developments. In a degree he must grow to look at his work and his business with the critical eye of an observer.

Business executives try to help the young engineer in the initial stage and to expedite his arrival at the second stage. The first period is susceptible to a tangible course of training and measured accomplishment. But a formal technical or business training course will not suffice to bring about all that is desired in the second period. The development of a man to be broadly useful is as much, if not more, a matter of his habit and attitude than it is of imposed training schedules.

Many young engineering graduates become successful as individual workers on technical aspects of business, but fail to adjust and develop to meet the broader specifications required in leaders of men. They frequently are unwilling to teach subordinates or to trust them with any responsibility. Others rest content in specialty engineering jobs and sit back with the attitude that they have arrived, and so it is not necessary to keep up the pressure. Still others are so busy with their specialty and with details that they lack the perspective to see that success as an engineer can be made the foundation to lead to success in higher executive positions. Still others are not fitted by nature to be other than individual technical specialists.

Industry executives watch these young men grow and know that a certain number will arrive at essential cog-wheel positions in the business. But first of all they seek the man who has the determination to overcome routine and the imagination and daring that comes from seeing distant goals. They like to see a young man rise through the normal series of plateaus to a peak of usefulness, and are ready to pay the rewards that go with this accomplishment.

Training for All Positions

When they start to work most young engineers are ambitious and full of enthusiasm. They want to go places in a hurry. Perhaps their ambition is quite selfish and personal and takes the form of desiring a wage increase every three months, and a position as vice-president in four or five years. They start out to work for themselves and not for the company. The first step in training these men is to change this attitude of selfish and rapid personal advancement. Perhaps the static and slow changing tempo of old established industries is not sufficiently understood these days. Industry expands slowly in income, plant, and personnel. It also is more complicated and functionalized so that it takes longer for a man to "learn a business" in a measure that makes him fitted for higher positions.

Much of industrial activity is repetitive with few changes and slow progress. Men are needed for this kind of job and a large number of young engineers are fitted into semi-static positions, but even so, these men must meet specifications that are broader than those involved in technical competency. They must measure up to the requirements of a good foreman as a minimum. But industry also needs the limited few that are creative; men with powerful and unsatisfied dreams and ambitions which will motivate them to put their talents to work to keep the business aggressive and progressive. Men are wanted with the imagination to conceive and the talent to accomplish despite obstacles.

Thus training is used to develop all kinds of men for all kinds of positions. This training is largely a matter of forming good habits by use of repetition and counsel. Little can be added to the natural ability of men, but they can be helped and developed. Industry tries to do its part by keeping them interested, in good physical and mental condition, and in a fertile environment. Executives give these men tests to try their initiative, mixing ability, judgment, and responsibility. They apply discipline as well as stimulation. They give opportunity for these men to form good habits in business as well as to use all their mental and personal assets. Business leaders try to have all employees seek more than a customary wage for customary work. An employee is developed to have the greatest value to the organization by training him to have his desires and ambitions focused, an interest in his work, and an aggressive and confident attitude toward it.

The addition of a man to a business organization involves more than an expense. It exposes the organization to possibilities for good and for evil. Each recruit has certain native qualities, such as intelligence, mental alertness, appearance, and personality. He has acquired other qualities, such as his attitude, his manners, his education, and his knowledge of the world. These acquired qualities are of equal importance to his native or hereditary qualities. Industry ranks of the greatest importance the character of an employee, that is, his individual philosophy of life and his personal standards of conduct.

The acquired qualities and character of a man can be

changed by education and experience, but this may be difficult. As an example, a young man who has been an ardent socialist in college with a hostile attitude toward the capitalistic system will not change this attitude because his employers tell him to do so. He is far more apt to seek disciples among his fellow employees and to become a disturbing element, because he is more interested in his cause than in his work. No one will gainsay his privilege of holding his opinions and trying to put them into operation but on the basis of equal fairness, no one can blame an industrial executive for declining to employ such a man.

In this connection many leaders in the business world are not sold on the idea that engineering graduates would be better material to employ if they had a so-called "broader culture" through more courses in economics and sociology. Too much evidence exists that the womb of many "isms" and challenges to the fundamentals of our American system is these departments of our universities to make them accept this as a method to liberalize and broaden engineers.

Despite the pressure on engineers to be liberal and cultured, it is not recognized that these qualities are largely attitudes rather than responses to knowledge. There seems to be no prescription for use in colleges to impart culture. Nor can one expect a young man in his formative years to have the experience and the perspective to deal with the broader aspects of humanity and civilization on an intelligent basis. He is more interested in getting a job, in mixing with his fellow workers, in his ability to live on $30 a week and in making good, than he is in theories of government of business conduct. It is doubtful if a few courses in any college will give him the wisdom and experience that comes with the years. They are more apt to infect him with half-baked ideas that handicap him when he faces his immediate job in life. This is to go to work and produce results.

No business manager will disagree with the statement that his hardest job lies in dealing with personnel. He knows that success or failure rests largely on a foundation of competent and happy employees. And happy is just as important as competent and often more difficult to achieve.

Problem of Reward

It is not particularly difficult to select and to train personnel. Yet in any going concern there is soon reached a stage wherein the personnel is trained and competent and the turnover low. The most difficult thing for the manager is to expand the business at a rate that will permit personnel to advance at a rate commensurate with their growth in competency and business capacity. We have reached a stage in this country wherein old established enterprises cannot grow larger and larger each year, or when the rapid introduction of new inventions or developments can be counted upon to add new departments, or to change existing processes and methods. Yet competent employees grow impatient if more compensation and added responsibility do not come to them at the rate deserved. This creates a difficult situation for both the business manager and his employees.

This American idea of more money and more responsibility for each year of service dates to expansion periods. All of us would like to see this cycle kept in balance because it builds better men, but how shall we overcome fundamental economic handicaps to its success, and how shall we improve the attitude and keep the enthusiasm of our employees when they are becoming more or less fixed in their economic position?

This is true despite the fact that business faces a new social and political situation today. The human factor is announced by political powers to be the dominating consideration in all industrial undertakings. The yardstick for measuring values in our present civilization is taken to be the well-being of the individual. This preferential position given to employees by law presents problems to both employers and employees. Leaders of industry have gone along developing large enterprises, multiplying the jobs for labor, applying power and machinery, stimulating the demand of the public for new products and, in general, making more goods at lower cost. They have thought that this program, together with the force of competition and the incentive for profit, leads to the most desirable social and commercial progress.

As a part of this plan industry considered its personnel as a foundation and sought to improve the economic position of employees through selling more goods at lower costs, so that purchasing power and wage rates could increase. And a firm part of this policy was a reward to the individual worker who showed ability above his fellows.

Employees on their part accepted this policy and sought to improve their economic position through meritorious achievement. Each man was more or less imbued with the idea that he could become president of his company, if he had the talent.

Under the new conception both employers and employees are put under controls that tend to stifle individualism and force uniformity. Business leaders are regimented and made to act according to fixed laws, and the employees are fixed by law into classes wherein promotion is a question of seniority instead of one of merit.

Experience indicates that the general industrial policy as carried out in the past has been sound, but some abuses, a growing complexity in national affairs, and social idealism have brought into play political and social forces of magnitudes equal or greater than economic realities in many instances, and have forced business leaders to give priority to personnel in their evaluation of the factors that make or break their enterprises. Without regard to economic fact or to the differences in human beings, both employers and employees are being forced into groups with arbiters and rulers appointed by the state under legal instructions to base decisions on the human element in business as the first consideration. Whether this is good or bad policy is a matter of opinion, but it does put upon both employers and employees new rules that may or may not fit economic conditions.

Present economic forces are already powerful to hold

industries to a slow growth, such as the large capital investments involved in expansion, and the years of effort required to get channels of distribution and trained employees established to sell products to the markets. Size and complexity work against the elasticity that is necessary to the expansion in numbers and the growth of rewards for employees. To these existing handicaps to building men into superior positions is now added the recent social legislation that makes employers and employees play the business game according to new rules.

Undoubtedly the first effect of the new laws is to slow up business expansion and to routinize the handling of personnel. Later, these laws, passed to prevent abuses, may not prove vitalizing tools for employers and employees to use to bring about business success. In seeking to train men for the needs of tomorrow any industrial manager can but guess what these new forces will do to his plans and programs. No one can say what the future holds, but no one can stop business action.

Thus it is a fact, that we are dealing with new conditions and new forces that add to the complexity of business, and make it more necessary than ever for executives to use care in the selection and training of man power to fit into business needs. Business will go on. Executives in industry will still strive to get young engineering graduates and to train them. The more complicated business becomes, the more necessary will it be to get the best possible men and to train them with diligence.

The Paradox of Social Progress

By ROBERT E. DOHERTY
MEMBER AIEE

Courageously facing a startling and controversial subject, a prominent engineer and educator here voices some questions and makes some suggestions that merit consideration. Brief discussions are invited

I PROPOSE to examine the significance of some current thought and trends in our social, economic, and industrial life. My primary emphasis will center upon the relationship which research, engineering, and education bear to social progress and welfare. I trust it is unnecessary for me to disclaim gifts as a soothsayer, or intention to indulge in the idle lamentations of a Jeremiah, even if what I say does relate to the future and does perhaps bear a disquieting note. Merely, I would analyze what seem to be dominating factors in the problem of social progress and indicate their implications concerning what we as a people shall have to do if we are to achieve an adequate measure of intelligent control of the forces that shape that progress. This is precarious business, however, because it involves some generalizations as to what constitutes intelligent control, what constitutes prevailing opinion among economists, what constitutes present trends. Certainly there is not unanimity of opinion regarding any of these. Nevertheless, all serious-minded citizens, and especially those who have direct responsibilities in any of these matters, are under obligation to form clear convictions and give them expression, and this is my purpose.

We are told by the economists that to maintain prosperity and social progress within the profit system, it is necessary continually to increase the efficiency of industrial production; that is, to produce more goods at lower cost. But this process, which involves the full power of science, invention, and engineering, increases rapidly the complexity of social organization; and even now that complexity is growing faster than our social understanding. Hence we face the paradox that this very improvement of production which would save us from economic and social collapse would apparently also impel us ultimately to the same tragic fate. In other words, the remedy and the ill seem equally fatal.

What is the answer? Is there any way out of this paradox of social progress? Can we afford to throttle engineering and invention and thus run the risks the economists would predict? If not, dare we encourage technological progress even at its present rate, let alone at an accelerated rate, and take the risks of social and economic confusion to which it is evidently leading us? Is there no way out of this situation? I think there is.

A Proposed Remedy

It is planned education. I am confident that we as a people have at least the capacity, if only we would utilize

An address presented at the University of Illinois, Urbana, April 21, 1938, on the occasion of renaming the materials testing laboratory The Arthur Newell Talbot Laboratory.

ROBERT E. DOHERTY is president of Carnegie Institute of Technology, Pittsburgh, Pa. He was graduated from the University of Illinois in 1909, and was employed by the General Electric Company until 1931, when he became professor of electrical engineering, and subsequently dean of the school of engineering, at Yale University. In 1936 Doctor Doherty assumed his present duties. He received the 1937 AIEE Lamme Medal "for his extension of the theory of alternating-current machinery, his skill in introducing that theory into practice, and his encouragement of young men to aspire to excellence in this field" (*EE, Mar. '37, p. 141; Oct. '37, p. 420–9*).

it, to solve the problem by bringing up new professional generations who can learn how to cope with these increasing difficulties. Then we could encourage technology and look forward with confidence. The only question in my mind is whether the required changes can be brought about in time—that is, changes in professional point of view that must precede changes in educational programs.

Thus, my thesis may be stated in general terms as follows: I believe that this country faces a serious dilemma with social confusion as the apparent outcome of either choice; that this dilemma can be resolved to the end of democratic ideals only by the long and difficult process of a planned education that will require some fundamental changes in policy; and that delay in such changes and in instituting a revamped educational plan may prove fatal to its success.

Let us understand the first premise. When the economists say we must increase the efficiency of industrial production if we would maintain prosperity and make possible, at the same time, a rising scale of living, they are merely saying, if I understand them, that we can't lift ourselves by our bootstraps. For illustration, if an industry is operating in a balanced state—that is, if it pays its bills, its wages, and a reasonable dividend; if it keeps its plant and equipment in repair and provides those reserves which intelligent accounting control would specify; and if in doing these things it uses its whole income—then under this balanced state, the only way it can earn funds with which to meet any increase in expenditures, such as wages or taxes, is to produce its goods or service at a lower cost. If an industry is obliged, on account of government regulation, taxes, or the demands of labor, to destroy this balance, and the industry is not able for one reason or another to meet the added cost by increased efficiency, then the ultimate result is bankruptcy. The railroads today are a good example. The coal industry is another. And if we judge from the present move toward further federal regulation, the magnificent communication system of this country will, in due course, be still another. The economists therefore tell us with good reason that we must increase the efficiency of industrial production and, at the same time, keep new demands upon the industrial income within the new income thus created. This is our first premise.

Then we face the compelling force of our second premise that science and engineering, which we would encourage, are rapidly increasing the complexity of social organization beyond our understanding. There would naturally be little satisfaction in building further the magnificent technological structure already begun, and upon it an increasingly complex social structure, only to have the whole affair tumble down upon us. Although I must say if I had the choice between this fate, on the one hand, and, on the other, that of living in a doomed, defeatist world in which science and engineering were throttled down, I should choose the first. At least it would be more fun while we were at it. In any case, we face the evident fact that even with our present rate of technological development, the consequent growth in complexity of social relationships has already surged beyond our understanding.

Each day reveals fresh evidence of this. Most of the councils in which important matters of national concern are being settled are not distinguished by a comprehensive understanding of the problems considered and by rational thought. What does distinguish them are strategy, show of force, emotion, and oratory. This froth of words and cunning takes the place which reason and understanding should occupy. Witness, for example, conferences on the relief problem, the T.V.A. controversy, the conflict of labor with industry and of labor with itself, the N.R.A., the Supreme Court squabble with its incredible and demoralizing aspects. Any newspaper will afford further illustrations. Indeed the evident lack of understanding of the problems themselves is not the worst of it; many of the leading minds in these situations seem not even to comprehend the necessity of understanding the problems they are trying to solve. But you may say to me that technology is not wholly responsible for all of this confusion; that congenital stupidity adds its share, as it probably has done since primitive man began groping for practical readjustments to his changing environment. And I should agree. But in those early days the physical environment did not change rapidly. Man had infinitely more time in which to readjust his life and thought. What technology is responsible for is a tremendously accelerated tempo of change. We are not, in this age, dealing with the creeping advance of a glacier; we are dealing with the dash of an airplane and the speed of light. And if we do not learn how to anticipate essential readjustments and to bring them about intelligently and with necessary promptness, we probably shall crash. That is the burden of our second premise.

If we accept these two premises, are we not forced to the conclusion that if we would retain the fundamental elements of democracy, our only hope is a planned education—an education that would cultivate social and economic understanding, humane appreciation, and a scientific attitude of mind?

But I have no hope of Utopia. Even with such an education we should unquestionably still have our troubles. There must always be controversy; there must always be stupid people who have a hand in affairs; and moreover the problems of social organization will, it seems clear, become more and more complex just as surely as time goes on. However, I should hope that the fruits of such an education might make it possible for us to grope our way out of an inevitable succession of crises by having here and there a thread of intelligent purpose to guide us, and here and there a person who could detect and follow it. Thus perhaps at least a general direction could be imparted to the clumsy, milling masses of a now confused democracy.

May we assume then that a planned education, supported by both technological and social research, promises to be a way out? If so what form should this take?

We should bring up new professional generations who can continue technological progress, who understand social relations and organization, who comprehend the effects of their work upon society, and who have arrived at a philosophy that is in harmony with the ideals of democ-

racy. The acquirement of such a philosophy and such a social understanding must naturally be expected of all professional groups, and certainly of none of them less than of engineering. However, my observations from this point on will bear primarily upon engineering, concerning which I feel some degree of competency to speak.

To our purpose, then, there are two equally important sides of the engineer's education. One is technological; the other social.

Technological Education

On the technological side the implications are clear. In the first place the student's program must be *increasingly* directed toward better understanding of fundamental principles of science and engineering, and toward greater ability in the processes of analytical and constructive thought. I stress *increasing emphasis* on both of these because there is, and must continue to be, progressive extension in both depth and area of scientific knowledge, and a commensurate extension in its engineering applications. The developments that advance the technological frontier no longer spring from clever inventions that rest on an elementary knowledge of science and the experiences of everyday life. Rather they depend upon deep knowledge of an expanding science that can be mastered only by long, painstaking study and research. Compare, for instance, the development of the early steam engine, cotton gin, and telegraph, with that of the modern high-pressure steam turbine, the radiobroadcasting system, the new coaxial telephone cable (involving a single circuit over which more than 200 conversations may be transmitted simultaneously), the airplane, and automobile. These miraculous developments of contemporary science and engineering are fruits of research, invention, and analysis that rested upon profound scientific knowledge. And future generations will go still deeper. Recognizing this, engineering education in undergraduate years must place more and more emphasis on fundamentals, thorough understanding, and constructive thinking; less and less upon details of subject matter and specialized skills. The latter can be learned in graduate work or on the job.

Another reason for turning increasingly to fundamentals is the problem of time. Engineering curricula are already loaded heavily with technical matters, and there is now pressure to add another year to the curriculum in order to load on more. This pressure must be reversed, because, as I shall indicate presently more time must be assigned to the essential task of cultivating a social understanding and humane appreciation. Whether or not another year is necessary for this new task is yet to be demonstrated. I do not think that it is. In any case, however, an appropriate time—say one-quarter of the total curriculum—should be allocated to the task. This will press the technical side of the program within still narrower time limits and hence press the major emphasis still further toward fundamentals.

This change in emphasis and distribution of time will be difficult to achieve for two reasons. First, many employers will have to change their minds. They must be willing to accept graduates who are more broadly educated and thus better equipped for the long run, but who must learn on the job some of the manipulative skills they now have upon graduation. And second, the faculty will have to change its mind. Each one of us on a faculty naturally is clear that his own course and everything in it are essential to a sound engineering education. Yet, however difficult the change may appear to be on both counts, it apparently must be made if the ends we seek are to be attained.

In proposing such change of emphasis I am not unmindful of the fact that many engineering graduates, perhaps the majority, will not participate directly in the pioneering side of scientific progress. They will be engaged in commercial and industrial activities for which a program cut out on the pattern of present curricula may be appropriate, but with the important exception that more time would be devoted to the social and economic side which I shall presently consider. This group of graduates is just as important, their work just as essential, to national progress as any other. Merely it is different. Also I am not unmindful of the practical problem of segregating student groups and of the increased cost. But these are secondary problems. The primary problem is to bring up professional generations appropriately prepared for the jobs and the responsibilities of citizenship that are ahead of them. And certainly one of the most important of these jobs is professional engineering leadership, and there must be appropriate programs for this in undergraduate, graduate, and post-college years.

Another implication of the plan on the technological side is increased facilities for research and education. There must be laboratories, and they must be supported by adequate staffs and equipment. The ideal type of laboratory for an educational institution is, in my opinion, one which houses under the same roof the research projects of staff and graduate students and also the exercises of undergraduates. Then the younger students are in contact, even if it is incidental, with the search for new scientific truth; they sense the thrill of accomplishment; they breathe the atmosphere of inspiration.

Social Education

Let me now draw your attention to the social side of the engineer's education. If his work creates wealth and physical comforts for society, but endangers social stability, then he ought to be more fully aware of what he is doing, its consequences, its dangers. His creative effort has been aimed at the development of higher speeds of travel and production, greater concentration of physical power, more efficient and extensive communication; it should now be aimed also at a more orderly adaptation of these developments to the social organization.

Indeed the engineer's professional place in society has rapidly become a very important one. He has been literally flung into industrial management and other responsibilities where social and economic elements are dominant, and he has had to learn to deal with these new responsibilities while on the job and with no fundamental

preparation such as he had had in engineering itself. On that side of management involving the cold facts of machinery, materials, and dollars and cents, I think we should all agree that he has been supremely successful; but not so on the human and social side. Yet his part on this side, both professionally and as an educated citizen, must become larger with time. I am not one who says it is the engineer's mission to save the country, but I am one who says that if it is to be saved, he must have a very definite hand in it. And he therefore must have an opportunity while in college to begin his educational preparation for this responsibility.

For his interest in these social changes and his ability to understand them will not come by chance. As a student he must begin to cultivate this interest and ability. Then when he encounters social problems he will at least have a start toward competency in studying them. Then he would be less likely to attempt to place human emotion in a simple formula or on a curve; he would be less likely to be persuaded by the lure of economic panaceas like technocracy or the rubber dollar; and he would realize that human affairs and social problems are even more complex than the ones he has dealt with in the physical world. He would be aware that there are extremely few simple relationships in the social sciences that stay put as do Ohm's law or Newton's laws of motion with which he has commonly dealt. And he would realize that instead of resting on rigid, permanent principles such as these, many social arrangements rest upon a philosophy that may shift, and shift quickly. What is right today may be wrong tomorrow.

These complexities are baffling to the student of physical science, because he attempts to use his rigid technical procedures to unravel them. One of the greatest educational fallacies I know is the assumption that the ability to solve problems in the field of physical science implies such ability in social and economic affairs. Indeed the reverse is probably true. When I was dean of engineering at Yale I urged students to take a course that has gained a national reputation—Human Relations in Industry given by Professor Elliott Smith. He told me that if possible I should send to him only juniors, not seniors, because he had found conclusively, year after year, that it took him two or three months longer with the seniors to break down the technical shell in which their minds were becoming enclosed; that their acquired habit of determining every problem with quantitative exactness had inhibited progress on the problems of his course which involved matters that could not be so determined. However this may be, I am clear from first-hand experience with engineering students who have undertaken to deal with social problems and from personal observation in industry that technical proficiency does not imply proficiency in dealing with problems involving human or social elements. The application of the scientific method in such problems requires something more. It requires knowledge of social evolution; it requires humane appreciation; and it requires an understanding of the difference between a philosophic doctrine and a physical law, and of the fickleness and power of human emotion. Without these, a keen scientific mind becomes naive when it meets a social problem.

How can the social side of the engineer's education be accomplished in the limited time? I am clear that it cannot be done by offering electives in the conventional subject-matter courses such as English, government, economics, history, and the like. Even if the entire curriculum were assigned to such credit-hour units, thus eliminating engineering, I still should not believe that the student could acquire the integrated, historical view of social development, the scientific attitude, and the ability to analyze complex problems in the field of social relations that we have considered. At least if one is to judge by the current professional contributions of those who pursued such a program when they were in college and now have public responsibilities in these matters, one is not impressed by the effectiveness of that educational plan. I am sure there must be a more effective approach, at least in the education of engineers.

I hope I shall not be misunderstood when I say the approach to the educational problem should be an engineering approach. By this I mean simply that we should define the problem in terms of the outcomes of intellectual accomplishment with which we would have the student emerge at graduation, and then set about designing, first, a program every hour of which throughout the four years would be aimed accurately at the achievement of those outcomes, and, second, a means of testing *at the end* whether those outcomes have been achieved.

Thus, for this side of the engineering curriculum I would recommend for all engineers a four-year program, consuming perhaps a fourth of the total educational time, that would lead to the following outcomes: (1) a clear historical understanding of the parallel growths of science and engineering, on the one hand, and social customs, relations, and institutions, on the other, and of how these have reacted on each other—in other words, a social consciousness and a historical perspective of social evolution, especially, but certainly not wholly, since the invention of the machine; (2) the ability to read purposefully in order to make a critical analysis of a problem involving social and economic elements and to arrive at an intelligent opinion about it; (3) the ability to organize thoughts logically and with purpose; (4) the ability to use the English language and thus express those thoughts effectively; and (5) a continuing interest in all these matters—in other words, the desire to become educated.

Then there should be a new approach in research. To interested observers on the side-lines the point of view of social and economic research appears to have become, like much of that in education, so specialized and the research itself so desultory that progress toward understanding such phenomena as a whole is seriously inhibited. However, whether the scholars and specialists in the several fields concerned would agree wholly with such observers' impression, no one, I dare say, would disagree with the proposal that more research programs should be organized in which the distinguishing characteristic was continuing study and the breakdown of departmental barriers; programs, in other words, in which a continuous effort was

made by research teams to understand social relationships as a whole and how these are affected by technological progress. This research is, of course, primarily the responsibility of social scientists, but engineers most certainly have an interest in it.

Stated in still other words, the programs should attempt to draw unbroken trunk lines of the parallel growth of technology and the social structure, from early beginnings down to and extending into the living phenomena of the present. They should be an integration as well as a search for new facts. Specific studies have been made by a multitude of investigators on labor relationships, the results of labor-saving machinery, employability, housing, racial relations, social security, cost of living, etc., etc. And such factual studies have been necessary of course to provide segments of the lines of growth referred to above. But all of the factual segments have not been provided, and, more important still, their positions in the lines have not been established. The lines are yet to be clearly drawn. And finally, the programs should be continuous: unrelenting scientific pursuits of the problem. Fundamental scientific results are less likely to issue from studies limited to a few months or a few years than from a continuous program with long-range objectives. The results of such research should be fed into educational programs and thus contribute to general understanding.

Application to All Professions

But I do not wish my thesis to become obscured by the details of educational and research procedures. I have attempted to emphasize what seems to me a critical situation, a dilemma facing this country, and to suggest a possible, even if very difficult, resolution of it. Social trends are apparently leading us toward social chaos. Economists tell us that this chaos is inevitable unless technology is encouraged so that the efficiency of industrial production can be increased. Yet chaos seems equally certain if technology is encouraged, because it increases beyond our understanding the complexities of social relations and organizations. Our only hope, it seems, is a planned education. We must cultivate social understanding and humane appreciation among all of the professions, and especially is this necessary for engineers who have the double responsibility of technological development and social welfare.

I have said the solution is difficult. Effective public understanding cannot be realized by a mere handful of broadly educated men; large numbers of them are necessary. There must be not only those who serve the general welfare directly in their professional capacities, but untold others who, as citizens that have had the opportunity of higher education, will give critical thought and support to measures initiated for the public good. The education of such a professional citizenry is a long-range process. But this is not the fundamental difficulty. Neither is the difficulty a lack of national wealth from which the proper development of research and education might be supported; nor is it that we are divided into political pressure groups; nor that there is not sufficient inherent intellectual capacity among our people. The fundamental difficulty is inducing mature minds to take a new view. Yet this must be done first of all. A new decision must be reached by the American people through their statesmen in politics, industry, finance, and education. It is the decision whether or not they are willing to pay the necessary double price for this program: the cost in money for new research and educational facilities; and the intellectual effort required in order to establish the educational policy just outlined.

Nevertheless, great as this double price may appear, the inevitable alternative price is infinitely greater. I mean the sacrifice of freedom. There are certain things to which we must cling at all costs. We must keep intellectual freedom; we must keep individual personal liberty to the greatest possible degree; we must keep incentives to constructive effort. These tongue-worn phrases still symbolize the American Dream. They represent ideals for which great sacrifices already have been made in life, treasure, and change of view. And it is unthinkable that as trustees of these gifts we should fail in the decision and action that would preserve them. I have said we as a people must make a decision. I have no fear that, given plenty of time, we should not make the right decision; I do have fear that under the now greatly increased tempo of life we may wait too long. The fundamental difficulty in our solution is complacency in professional America, a tendency toward frozen, or jelled, mental states. Will professional men on whose shoulders this responsibility rests, act in time? Or will the natural ossification of view as we reach the age of professional decision prevent our taking the initial step that is necessary before the younger generations, yet in college, can have the opportunity to prepare themselves?

Graphical Field-Plotting Methods in Engineering

TO EXHIBIT the great range of problems that may be solved with comparative ease by graphical means, even though they may be very difficult to solve analytically, is the object of this paper.* The most familiar examples of field plotting are used for solving the Laplace equation $\partial^2 v/\partial x^2 - \partial^2 v/\partial y^2 = 0$, solutions of which are known as "harmonic" functions. This equation, as well as its three-dimensional analogue, has a wide range of application, and receives more comprehensive treatment than does any other type of equation.

Succinct analyses of axially symmetric fields, plane fields in current-carrying regions (the Poisson equation), torsion of shafts of constant cross section, viscous flow in pipes, and torsion of shafts of circular but variable cross section make up the remainder of the paper.

* Abstract of 1938 AIEE summer convention paper number 38-59, by Hillel Poritsky, which will be published in full in TRANSACTIONS.

Influence of Utensils on Heat Transfer From Range Units

By W. GEORGE SHORT

Many different types of cooking utensils and electric range surface units are available for domestic use. The heat-transfer efficiencies of various combinations of utensils and units are different, as shown in this article, and from the standpoint of over-all efficiency of heat transfer, differences as great as 24 per cent have been found.

USE of electricity for cooking has increased rapidly, largely because of the cleanliness, safety, and ease of control of the electric range. In a previous investigation,[1] W. James Walsh studied the heat-transfer efficiencies of various range surface units. He did not, however, investigate in detail the effect of various cooking utensils on the heat-transfer efficiency.

In the present investigation, the heat-transfer efficiencies of the various cooking utensils, when used on different range surface units, were studied in detail. The transfer of heat from the unit to the contents of the utensil can take place by conduction, by radiation, or by both. It is apparent, therefore, that the type of range unit, and the material and shape of the utensil, will influence the transfer of heat from the range unit to the utensil's contents.

Range Units and Utensils Used

The range units used in this investigation are shown in figure 1, and will be referred to as units *A*, *B*, *C*, and *D*. Each unit is rated at 1,200 watts, and each was tested when installed in the particular electric range with which it was designed to be used. The units and ranges were of the most modern type available at the time the tests were performed.

The utensils used in this study are included in figures 2 and 3. These represent not only conventional utensils, but also, the extremes from black-bottomed aluminum to glass. With transparent glass utensils, the contents are heated partly by radiation; with the other utensils used, however, all of the heat reaches the utensil either by conduction or radiation and must pass through the utensil to the contents by conduction.

The base of the glass utensil was, as indicated in figure 3, slightly smaller than that of the other utensils tested. Its dimensions were such that it did not cover completely the range unit as did the other utensils; however, the sides flared out permitting additional radiant energy to be absorbed. The black-bottomed aluminum utensil used was one of conventional type coated, by the manufacturer, with a black lacquer for these heat-transfer investigations, and is not available commercially. Attention is called to the fact that apparently very little is known regarding the efficiencies of the various types of blackening materials.

As indicated in figure 3, one of the enamel-ware utensils was made with a bottom of black enamel both inside and outside. The sides were of light-green enamel. The stainless-steel utensil of figure 3 was surfaced with a "satin finish" in contrast to the "polished finish."

It may also be noted in this same figure that the bottom surfaces of the glass and of the steel containers were not flat, so that the entire surfaces could not be in direct contact with the range unit.

The handles of the aluminum and the black-bottomed enamel-ware utensils were removed during the tests, since they were not integral parts of the utensils.

The specific heats, weights, and capacities of the various utensils are shown in table I.

Measurement of Energy Input to Range Units

During the tests the input of electrical energy to the range unit was measured with a calibrated portable induction test meter (rotating standard). A constant value of alternating voltage as indicated by a voltmeter was maintained on the range unit during each test. Both the potential leads of the test meter and those of the voltmeter were connected directly across the range unit. An investigation showed that the error caused by the presence of the test meter was negligible, but that a correction was necessary for the energy consumed by the voltmeter. Measurements of time were made with an accurate stop watch.

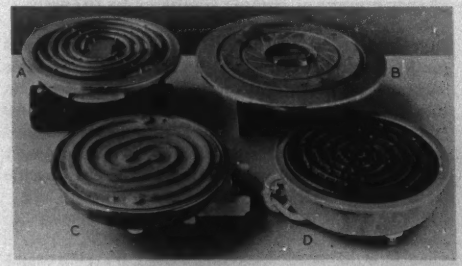


Figure 1. Range units used in investigation—rated 1,200 watts

From the observations made, the energy input W_i in calories is given by the equation[1]

$$W_i = 860.4\,(K_h R - E^2 t/3600r) \qquad (1)$$

An article based on a paper presented at a joint meeting of the AIEE Portland Section and the Oregon State College Branch, Corvallis, Ore., May 15, 1937.

W. GEORGE SHORT, when the paper was prepared, was a senior student in electrical engineering at Oregon State College, from which he was graduated with the degree of bachelor of science in electrical engineering in 1937. He now is with the General Electric Company, Schenectady, N. Y.

1. For all numbered references, see list at end of article.

Table I. Specific Heats, Weights, and Capacities of Utensils

Utensil	Specific Heat	Weight (Grams)	Rated Capacity (Quarts)
Black-bottomed aluminum	0.216	430.5	2.0
Bright-bottomed aluminum	0.216	418.8	2.0
Black-bottomed enamel	0.17 (approx.)	991.2	3.0
White enamel	0.17 (approx.)	475.5	2.0
Stainless steel	0.22	403.2	2.0
Glass	0.017	659.3	2.0

Table II. Heating Time Required for a Rise in Temperature of 75 Degrees Centigrade of Utensil Contents

Cooking Utensil	Time (Minutes)			
	Unit A	Unit B	Unit C	Unit D
Black-bottomed aluminum	9.2	11.4	12.5	13.1
Black-bottomed enamel	9.6	13.0	12.9	13.4
Bright-bottomed aluminum	9.8	11.9	14.0	15.9
Stainless steel	10.0	11.4	13.8	15.2
White enamel	10.8	13.9	14.2	14.1
Glass	11.8	16.1	16.0	15.2

where K_h is the constant of the test meter in watt-hours per revolution, R is the revolutions of the test meter, E is the voltage impressed on the unit, t is the time in seconds during which the unit is energized, and r is the resistance in ohms of the voltage coil.

Measurement of Energy Transfer to Utensils

For these measurements the general method and precautions described[1] by Walsh were followed, and the same calibrated resistance thermometer was used for temperature measurements. Equal amounts of water (1,250 grams or 2.76 pounds) were used in each utensil

The energy W_a in calories transferred from the range unit to the utensil and the water it contained is given by the formula

$$W_a = (C_p W_p + C_w W_w)(T_2 - T_1) \quad (2)$$

where C_p is the specific heat of the utensil, W_p is the weight of the utensil, C_w is the specific heat of the water, W_w is the weight of the water, T_1 is the temperature at the start of the tests, and T_2 is the temperature at any time during the test period.

Calculations of Efficiencies of Heat Transfer

The efficiency of heat transfer from the element to the contents of the utensil is the ratio of the energy input to the contents divided by the energy input to the range element. That is, the heat transfer efficiency in per cent is the ratio of the energy as given by equation 1, or

$$\eta = W_a/W_t \times 100 \quad (3)$$

This value is the *over-all efficiency*[1] from beginning to end of the test.

The *instantaneous efficiencies*,[1] which take into consideration the input and output at a given instant only, may be obtained from input-output curves by determining the slope of those curves at each point. Mathematically, the instantaneous efficiency is

$$\eta = dW_a/dW_t \times 100 \quad (4)$$

Fundamentally, equation 4 consists of the ratio of two time rates of change, that of the input and of the output. Walsh has compared[1] these two efficiencies to the all-day and instantaneous efficiencies of a transformer.

Experimental Procedure

In general, the experimental procedure[1] perfected by Walsh was followed in this study. One important exception was the method used to prevent excessive evaporation from the surface of the water in the utensil during the tests. Much trouble was experienced by Walsh in obtaining a uniform film of Apiezon oil over the water surface. In these tests, therefore, a sheet of waxed paper, cut to fit closely the inside of the utensil, and pierced for the thermometer leads, was used. A small quantity of Apiezon oil was placed around the edges and the thermometer leads to make a better seal.

From the experimental data, the *over-all* efficiencies were calculated as discussed in a previous section. The *instantaneous* efficiencies were obtained from input-output curves. These efficiencies are the slopes of the curves at any point. These slopes were determined by the use of the "mirror rule" or "tangent meter" described by Schweitzer.[2]

Figure 2. Bright- and black-bottomed aluminum utensils

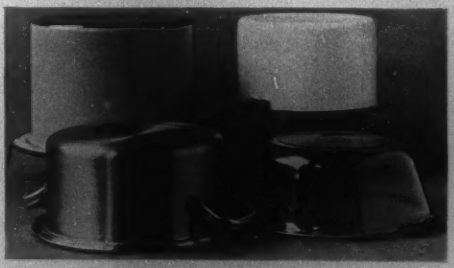


Figure 3. Black-bottomed enamel, white-bottomed enamel, stainless steel, and glass utensils

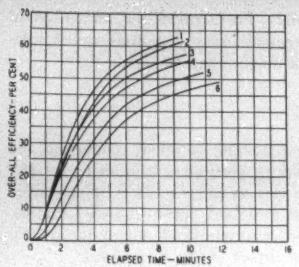


Figure 4. Type *A* unit

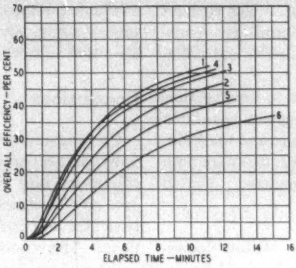


Figure 5. Type *B* unit

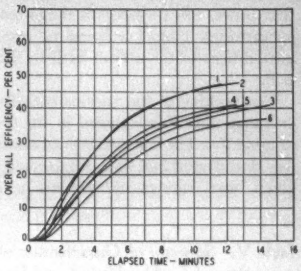


Figure 6. Type *C* unit

Figures 4–7. Over-all efficiencies of electric range surface units used with several types of utensils

Unit at room temperature at start of test
Weight of water 1,250 grams or 2.76 pounds

1—Black-bottomed aluminum
2—Black-bottomed enamel
3—Bright-bottomed aluminum
4—Stainless steel (satin finish)
5—White enamel
6—Glass

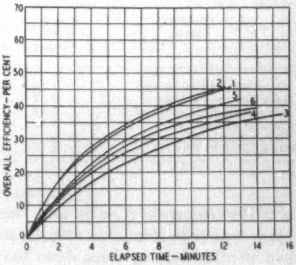


Figure 7. Type *D* unit

Results of Tests

The results of the heat-transfer efficiency tests on the various cooking utensils and range units are summarized by figures 4 to 7 and accompanying tables, which indicate the variations in transfer efficiency for each utensil on each range unit.

The speed of each utensil when used on the various range units is indicated in table II. As a measure of the speed or heating time of each combination, the time required for a rise in temperature of 75 degrees centigrade of the contents of the utensils was arbitrarily chosen.

In table III are shown the over-all efficiencies for a 75-degree-centigrade temperature rise in the contents of each utensil when used with the various range units. These values were taken from figures 4, 5, 6, and 7 by applying the heating-time values of table II to these figures and noting the corresponding over-all-efficiency values. These values are comparable to the watt-hour input to each combination to obtain the same temperature rise with the same contents in the utensil. All other factors being disregarded, the over-all efficiency is the true measure of the efficiency of each combination.

The maximum instantaneous efficiencies obtained on each range unit with each different utensil are summarized in table IV. The maximum instantaneous efficiency values are the limiting values approached by the over-all efficiencies of figures 4 to 7.

Table III. Over-all Efficiency for a Rise in Temperature of 75 Degrees Centigrade of Utensil Contents

Cooking Utensil	Over-all Efficiency (Per Cent)			
	Unit A	Unit B	Unit C	Unit D
Black-bottomed aluminum	62.7	52.0	48.0	46.5
Black-bottomed enamel	61.6	48.0	47.5	47.5
Bright-bottomed aluminum	57.5	50.0	41.0	37.5
Stainless steel	55.7	51.0	41.5	40.0
White enamel	52.0	43.0	42.0	43.5
Glass	49.1	37.5	37.5	40.5

Table IV. Maxium Instantaneous Efficiencies for Each Combination of Utensil and Range Unit

Cooking Utensil	Maximum Instantaneous Efficiency (Per Cent)			
	Unit A	Unit B	Unit C	Unit D
Black-bottomed aluminum	76.8	65.0	58.2	58.1
Black-bottomed enamel	74.5	53.6	60.0	53.1
Bright-bottomed aluminum	70.5	63.5	51.7	49.2
Stainless steel	68.0	56.0	50.0	40.0
White enamel	66.5	47.8	50.0	53.3
Glass	61.5	49.9	47.8	46.6

Discussion of Experimental Results

Since the purpose of this investigation was to study the efficiencies of various utensils and range units, the experimental results will be discussed for these combinations, rather than for the utensils and range units separately. It is, therefore, convenient to summarize the results of tables II, III, and IV in table V.

A brief explanation of this table will now be given. Referring to column *A* of table II it may be seen that the contents of a black-bottomed aluminum utensil on range unit *A* reached a temperature rise of 75 degrees centigrade in a shorter time than any other combination. The black-bottomed enamel utensil was second in heating time, the bright-bottomed aluminum utensil was third, and so on. The utensils are accordingly arbitrarily rated in table V in

that order, when used with range unit *A*. This element operated at a high temperature and accordingly transmitted heat to the utensil both by conduction and radiation.

The ranking of the various utensils as to heating time on range unit *B* is included in the corresponding column of table V. The black-bottomed aluminum and the stainless-steel utensil had the same heating time, and were both given "first" ratings, second place being omitted. Unit *B* is a low-temperature range unit, and the fact that the black-bottomed aluminum and the stainless steel utensils had identical heating times shows that this unit transmits but little heat by radiation.

Table V. Summary of Characteristics of the Various Combinations of Cooking Utensils and Electric Range Units

Cooking Utensil	Heating Time With Range Unit: A	B	C	D	Over-all Efficiency With Range Unit: A	B	C	D	Instantaneous Efficiency With Range Unit: A	B	C	D
Black-bottomed aluminum	1	1	1	1	1	1	1	2	1	1	2	1
Black-bottomed enamel	2	4	2	2	2	4	2	1	2	4	1	3
Bright-bottomed aluminum	3	3	5	6	3	3	5	6	3	2	3	4
Stainless steel	4	1	3	4	4	2	4	5	4	3	4	6
White enamel	5	5	4	3	5	5	3	3	5	6	4	2
Glass	6	6	6	4	6	6	6	4	6	5	6	5

Range unit *C* operates at a higher temperature than does *B*, and again the results indicate that transfer by radiation occurs. This is further brought out by the open-wire unit *D*. With this unit much heat transfer apparently takes place by radiation through the glass utensil and directly to the contents as the last item indicates. It is significant that the black-bottomed aluminum pan has the shortest heating time on all units.

The over-all-efficiency ratings of table V are obtained from table III. These efficiency ratings also show the superiority of black-bottomed utensils on units such as *A* which operate at high temperature. The general superiority of the black-bottomed aluminum utensil is again apparent.

Similar conclusions can be drawn from the instantaneous efficiency ratings. Again the advantage of black-bottom utensils on high-temperature units is evident, as is also the general over-all superiority of the black-bottomed aluminum utensil.

A general figure of merit or a resultant rating for each utensil is possible from table V. Thus, if all the ratings of each utensil on the various units are added, and this sum is then divided by the number of ratings, such a figure of merit is obtained. These combined ratings are as follows: black-bottomed aluminum, 1.17; black-bottomed enamel, 2.42; stainless steel, 3.67; bright-bottomed aluminum, 3.83; white enamel, 4.17; and glass, 5.5. In this classification, a low number indicates a general superiority of the cooking utensil for all electric range work irrespective of the type of range unit with which it is used. This applies, of course, only to the utensils and range units tested. These are, however, representative of the types available commercially. Furthermore, the comparisons of table V apply only when the units are consuming full wattage; that is, with the range switch on high.

Conclusions

Cooking utensils combining optimum conduction and radiation heat-transfer properties result in higher transfer efficiencies with the various range units. Differences in over-all efficiencies as great as 24 per cent were found between the best and poorest utensil and range unit combinations. The economic aspect of this is apparent.

For highest heat-transfer efficiency, the bottom of the cooking utensil and the top of the range unit should at all times be in intimate contact. To accomplish this, the bottom of the cooking utensil should be flat, and should not warp during use on the range element.

These tests indicate that with units operating on intermediate and low positions of the range switch, utensils which are especially designed to absorb energy by radiation and conduction should not show transfer efficiencies much greater than those which absorb energy largely by conduction alone.

References

1. Heat Transfer Efficiency of Range Units, **W. James Walsh.** Electrical Engineering, volume 56, August 1937, pages 953–8.

2. The Tangent Method Analysis for Indicator Cards of Internal Combustion Engines, **P. H. Schweitzer.** Bulletin No. 35, Pennsylvania State College, September 1926.

Absolute Power Factor of Air Capacitors

STANDARD air capacitors are used with measuring equipment of high sensitivity for comparison with test capacitors in investigations such as the study of dielectric materials; therefore the absolute power factor of the standard should be known. In the investigation reported in this paper,* seven air capacitors of different types of construction were studied. A method of determining the absolute power factor of an air capacitor was developed, and data were obtained on the effects produced by the degree of polish of the electrode surfaces, by the width of gap between the measuring electrode and its guard ring, and by the presence of water films on the plates.

Experimental results showed that in an air capacitor with brass plates whose surfaces are clean, dry, and free from oxides and dust, the absolute power factor is independent of the voltage stress up to 50 volts per mil, varies inversely with separation between plates, is not affected by the roughness of the surface, and is independent of the width of the gap between guard ring and measuring electrodes. High atmospheric humidity was found to increase the power factor even when the capacitor was enclosed in a substantial metal box.

* Abstract of 1938 AIEE summer convention paper number 38-96, by W. B. Kouwenhoven (F'34) and E. L. Lotz (A'38), which will be published in full in Transactions.

Graphics in the Solution of Complex Quantities

By E. C. GOODALE
ASSOCIATE AIEE

IN THE solution of a-c network problems there are two common methods of attack. In one the system is reduced to its equivalent impedances, and in the other to its equivalent admittances. The electrical quantities of a series circuit are determined most simply by finding first the impedances of the parts that are in series, then solving for the common voltage (if it is not given) and for the voltage drops. A multiple circuit is solved most simply by expressing it in terms of its admittances, then solving for the currents in the branches. If combinations of the two types of circuits are involved, the solution is simplified by using either all impedances or all admittances.

This may be done graphically, and certain well-known simplifications or equivalent networks may be solved graphically, without the necessity of the usual multiplication and division of complex quantities in solving the equations.

The process described here applies to the multiplication and division of complex quantities by graphical means, the only tools, aside from paper and pencil, being a straight-edged rule and a compass. It involves no trigonometric tables, and protractors are unnecessary, although a protractor or 90-degree "T" mark on a triangle is useful in laying off the 90-degree relations.

Multiplication of Complex Quantities

Consider two complex quantities $z_a = r_a + jx_a$ and $z_b = r_b + jx_b$. In accordance with the established rules of the algebra of complex quantities, their complex product is equal numerically to their numerical product and lies at a characteristic angle, with respect to the reference line, equal to the sum of the characteristic angles of the two quantities. The absolute value of their complex product therefore is $|z_a| \cdot |z_b|$ and intersects the base line at an angle $(a + b)$ degrees, where $a = \tan^{-1}(x_a/r_a)$ and $b = \tan^{-1}(x_b/r_b)$.

Figure 1 shows a simple graphical multiplication of z_b by z_a. Lay off r_a along the reference line, and at the tip of r_a lay off x_a in its proper relationship to r_a, thus determining point A on the diagram. With OA as a temporary reference line, lay off r_b along OA and draw x_b in its proper position with respect to r_b, determining point B. Along OA lay off length $OU = 1$. Draw UB. From A draw AB' parallel to UB and intersecting produced OB at point B'.

From the similar triangles OUB and OAB,

$$OB'/OA = OB/OU \text{ or } OB' = OA \cdot OB/OU$$

Therefore

$$OB' = z_a z_b/1$$

It is evident from figure 1 that the line OB' lies at an angle $(a + b)$ degrees with respect to the reference line. If the construction of figure 1 throws point B' off the paper, then instead of unit point U, lay off along OA, or OA produced, a longer line $OT = 10$, as in figure 2. Draw TB. From A draw AB' parallel to TB and intersecting OB at point B'. Length OB' is one-tenth the product $z_a z_b$. Therefore, when this construction is used, the length OB' should be multiplied by ten. In a similar way any desired multiplier may be adapted to the diagram, whatever the range of values covered by z_a or z_b.

Figure 1. Graphical solution of the complex product of two impedances Z_a and Z_b

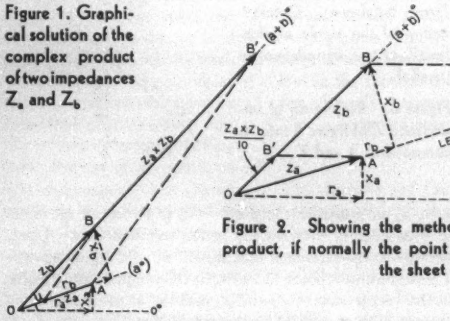
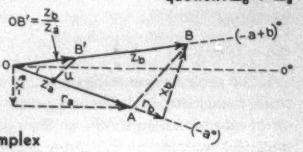


Figure 2. Showing the method of solving for a complex product, if normally the point B′ falls beyond the limits of the sheet of paper

Figure 3. Solution of a complex quotient $Z_b \div Z_a$



Division of Complex Quantities

Figure 3 shows z_b of figure 1 being divided by z_a. By established rules for the division of complex numbers, their complex quotient is numerically equal to their numerical quotient, and has a characteristic angle equal to that of the dividend minus that of the divisor. For figure 3 this angle is $(b - a)$ degrees. At right angles to the reference

Based upon a prize paper "A Graphical Method of Multiplying and Dividing Complex Quantities and Its Uses in the Solution of Impedance Networks," presented before the AIEE Seattle Section, March 28, 1938, at a prize paper meeting.

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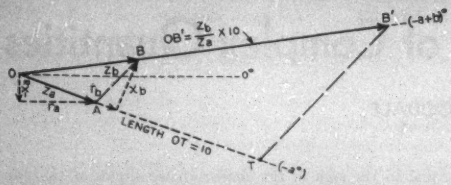

Figure 4. This type of graphical solution may be used to magnify the quotient line of a complex division by any desired amount, if normally it would be too small to interpret accurately

line lay off $-x_a$, and from the tip of $-x_a$ lay off r_a parallel to the reference line, thus determining point A. With OA as a temporary reference line, lay off r_b along OA and x_b in its proper position with respect to r_b, determining point B. Along OA lay off $OU = 1$. Draw AB. From point U draw UB' parallel to AB and intersecting OB at B'. From the similar triangles OAB and OUB,

$$OB'/OU = OB/OA$$

Therefore

$$OB' = OB \cdot OU/OA = z_b/z_a$$

If the construction of figure 3 throws point B' too close to O, then instead of the unit point U, lay off along OA or its extension length $OT = 10$ (or any other convenient multiple) as in figure 4. Draw AB. Draw TB' parallel to AB, to intersect OB or its extension at point B'. Length OB' is ten times the quotient z_b/z_a; therefore, divide the length OB' by ten, or by whatever multiplier may have been used for OT.

Where complex numbers are arranged in the form of a multiplication and a division, as in the expression $z = z_a z_b/z_c$, it is possible to simplify the multiplying and dividing operation by using any desired length as reference distance in place of the unit distance. It will clarify the diagram to take one of the quantities, such as z_c, as a reference distance.

A Simple Application

Although this graphical method may be extended to embrace the analysis of rather complex networks, its convenience and simplicity may be demonstrated adequately by the solution of a relatively simple circuit. Consider, for example, a circuit consisting of two impedances Z_a and Z_b in multiple. The single equivalent Z of such a combination is determined by the well-known expression $Z = Z_a Z_b/(Z_a + Z_b)$, where all quantities are complex. This means that the numerator is equal to the numerical product of Z_a and Z_b, and the denominator is the vector sum of Z_a and Z_b. The characteristic angle of Z is $(a + b - c)$, where $a = \tan^{-1} X_a/R_a$; $b = \tan^{-1} X_b/R_b$; and $c = \tan^{-1} (X_a + X_b)/(R_a + R_b)$, with respect to the reference line.

Figure 5 shows the graphical solution for Z, the single equivalent of the two impedances $Z_a = 5 + j3$ and $Z_b = 4 + j6$ in multiple. Lay off $-X_a$ and $-X_b$ at an angle of -90 degrees with respect to the reference line. Then, parallel to the reference line, lay off R_a and R_b, as shown. This determines point C. Length OC is equal numerically to the vector sum of Z_a and Z_b and lies at an angle of $-c$ degrees with respect to the reference line.

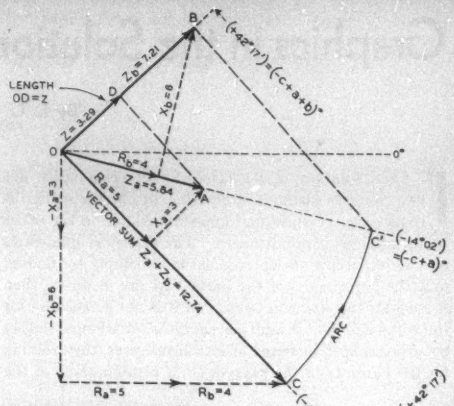

Figure 5 (above). Determination of the single equivalent Z of two impedances in parallel

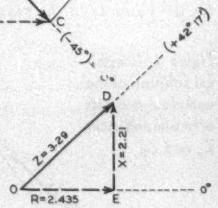

Figure 6. Resolution of impedance Z of figure 5 into its components R and X

With OC as temporary reference line, lay off R_a along OC and X_a 90 degrees ahead of OC to determine point A. OA is equal numerically to Z_a and lies at an angle of $(-c + a)$ degrees with respect to the reference line. With OA as temporary reference line, lay off R_b along OA and X_b 90 degrees ahead of OA to determine point B. Length OB is equal numerically to Z_b and lies at an angle of $(-c + a + b)$ degrees with respect to the reference line.

With O as center and radius OC, describe arc CC' cutting OA produced at C'. Draw $C'B$. Draw AD parallel to $C'B$ and intersecting line OB at point D. Length OD then is equal to Z, the single equivalent of Z_a and Z_b in multiple, and it lies at the correct characteristic angle $(-c + a + b)$ or $(a + b - c)$ degrees with respect to the reference line. Figure 6 shows the resolution of Z into its quadrature components, R its equivalent resistance, and X its equivalent reactance. From D draw DE perpendicular to the reference line. Then length $OE = R$ and length $ED = X$. The construction of figure 6 usually would be made on the diagram of figure 5. It was omitted there in order to make figure 5 clearer for the main construction.

Both reactances in the multiple circuit were assumed to be inductive. Had one reactance been capacitive, its direction in the diagram would have been exactly the reverse of those taken by the inductive reactances in figure 5.

Sterilization by Ultraviolet Radiation

By SAMUEL G. HIBBEN
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A new use for electricity rapidly is developing in the field of sterilization through controlled applications of radiation in limited portions of the ultraviolet spectrum. Such radiation has been known sketchily for its abiotic properties, but a practical knowledge leading to commercial applications has evolved only recently from careful segregation of different wave lengths, the elimination of certain very short-wave radiations that seem undesirable, and the perfection of a means of measuring such radiation quantitatively. The sterilization of foods and food containers, various utensils, and articles subject to mold or fungi growths, and the reduction of air-borne bacteria seem destined to characterize this new tool in the form of commercial tubular lamps as one of man's strongest instruments in combating disease and reducing spoilage losses.

THROUGHOUT the entire range of the electromagnetic or ether spectrum, from radio wave lengths 20 miles long to the minute lengths of 0.0001 Angstrom impinging upon the earth from interstellar space (the Angstrom being a wave-length linear distance of one ten-millionth of a millimeter, or approximately four billionths of an inch) man has developed the means of producing and exactly recording all the various radiations except those termed the cosmic rays or those that may consist of rapidly pulsating energies having wave lengths of the order of 0.01 Angstrom or less (figure 1). The analysis and the synthesis of radiation stretching far to both sides of the visible or rainbow spectrum (to which the eye is attuned) has been one of the most admirable contributions of physical science. The knowledge of these energies is not recent, but the practical applications thereof to human needs and human services has expanded rapidly in the last few decades, and seems destined to expand still further since the subject is receiving a concentration of attention in modern research.

One of the most intriguing regions now being intensively explored is generally classified as the subvisible or ultraviolet portion of the spectrum, extending generally from the 4,000-Angstrom wave length of deep purple (visible) light to the shortest wave lengths that may be transmitted through fused quartz, or for any reasonable paths through air. Since the limit of quartz transmission is roughly 1,700 Angstroms and of air but slightly shorter, we may assume that the region under practical consideration extends from extremely long X-ray radiations, perhaps 1,000 Angstroms, up to the beginning of retinal sensitivity.

While it is true that the term "ultraviolet" is applied to this entire portion, yet recent knowledge has suggested the division of ultraviolet radiations into four portions, not sharply defined as to wave-length limits, but rather classified in accordance with the peculiar and quite differing properties. The simplest form of this division is as follows:

Fluorescent or near ultraviolet	4,000 to 3,300 Angstroms
Biologically effective or erythemal region	3,300 to 2,800 Angstroms
Abiotic or sterilizing region	2,900 to 2,000 Angstroms
Ozone-producing region	2,000 Angstroms to limits of air transmission

The latter two portions, or radiation having wave lengths shorter than about 2,900 Angstroms must be man-made—such radiations do not reach the earth's surface from the sun. The third portion, or the abiotic region, is the one that challenges our immediate attention since the radiations of these wave lengths when properly applied can aid quite definitely in the prolongation of human life and in the betterment of living conditions.

The lethal effects on microorganisms and fungi constitute the distinguishing property of such radiations, and the job that is being done today encompasses the perfection of a technique whereby nature can be aided in man's fight against disease, and whereby certain economic losses, especially in the handling and storage of food products, can be reduced. History is likely to record that the development of a simple practical means of destroying bacteria was one of the most important contributions of electrical engineering to the well-being of man.

When properly applied, short-wave radiation unquestionably does kill bacteria rapidly, and destroys the spores of fungi and often the fungus itself if it is superficial.[1] An index of the destructive power on certain microorganisms is given by figure 2,[2] showing that the minimum energy, or the greatest effectiveness, is with radiation of about 2,600 Angstroms in wave length, and that the required amount of energy rises tremendously when radiations much longer than some 2,900 Angstroms are used. Under the impact of the peculiar energy there appears to be a coagulation of plasma, surface blistering, and disintegration as represented by the conditions of paramecia shown in figure 3.

Based upon an address presented originally at a meeting of the AIEE Ithaca Section, November 5, 1937; subsequently revised and brought up to date.

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P. W. BLACKBURN is in the special products engineering department, lamp division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., supervising laboratory production of developmental electronic devices and peculiar radiators.

1. Koch 1889; Henri 1912; Newcomer 1917; Bayne-Jones and Van der Lingen 1923; Gates (reports of Rockefeller Foundation) 1929, 1930. See other references in Laurens "The Physiological Effects of Radiant Energy," 1933.

2. Gates, Harvard University Research, Rockefeller Foundation; see Laurens "Physiological Effects of Radiant Energy," 1933.

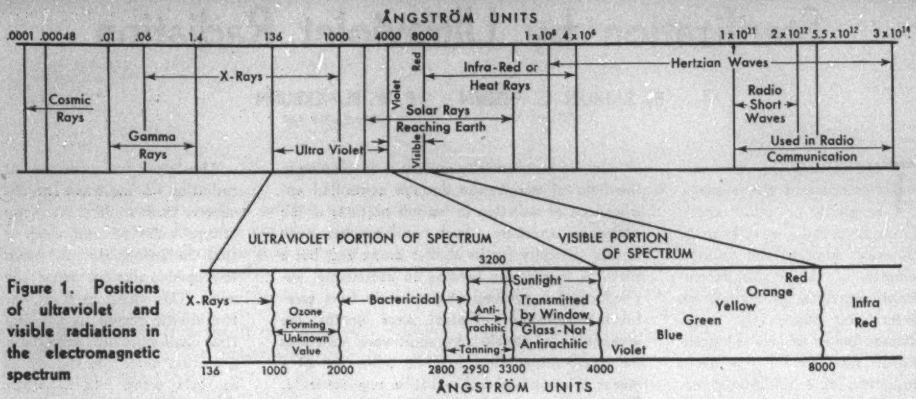


Figure 1. Positions of ultraviolet and visible radiations in the electromagnetic spectrum

The choice of the quality of radiation is critical. This can be appreciated better when we recall the entirely different colors of *visible* radiation, or light, and note that all the rainbow colors are produced by wave lengths that in the extreme will differ by but some 35 hundred-thousandths of a single millimeter! Sensuously, blue light is decidedly different from green, yet on the wave-length scale the difference is a seemingly negligible five hundred-thousandths of an inch! Thus, radiations having but the slightest wave-length differences may have quite varied properties physiologically.

Since abiotic or bactericidal radiation in any appreciable concentration is screened away from the earth's surface in the transmission of sunlight through the atmosphere, we must resort to an artificial production through the ionization of gases or vapors. One of the most practical methods is to develop an electric arc or discharge through mercury vapor at very low pressure in a glass tube or suitable container (figures 4 and 5) and emitting selected wave lengths needed for the particular job at hand. One such commercial device recently introduced under the trade-mark "Sterilamp" emits more than 80 per cent of its radiant energy at the wave length of approximately 2,600 Angstroms, and hence is a very potent and practical tool.

Energy of this wave length, at the low concentration found in the proper installation, will not penetrate the human skin sufficiently to bring about any known physiological effects. Under prolonged exposures (Laurens, Rentschler) there may be slight pigmentation or tan, and a highly concentrated overdose will produce erythema, but differing from normal sunburn. Conjunctivitis is the chief thing to guard against if working close to an exposed source, but ordinary glass protects the eyes adequately.

The Sterilamp consists of an evacuated tube some one-half inch in diameter and of varying lengths (figure 5) into the ends of which are sealed special metallic electrodes coated with such electron emitting material as barium and strontium oxides, designed to minimize voltage drop. Into the tube is inserted a small quantity of inert gas, or a mixture of gases, which permits ionization at normal room temperatures and thus allows the arc discharge to become established instantaneously when the electric power is applied to the tube terminals, and at reasonable voltage. This starting voltage is in general also a function of the tube length, ranging in the commercial product from some 400 to 800 volts.

In addition, the tube contains mercury vapor at a pressure of from four to ten millionths of an atmosphere—a pressure which results in the emission of a negligible amount of radiant energy in the visible spectrum but produces the well-known ultraviolet mercury lines, chiefly the 2,537- and 3,650-Angstrom wave lengths. The quality of the special glass of this lamp is carefully selected so as to obtain maximum transmission of wave lengths longer than some 2,000 Angstroms (65 per cent at 2,537 Angstroms) but to absorb rather definitely such shorter wave lengths as the 1,850- and 1,940-Angstrom bands.

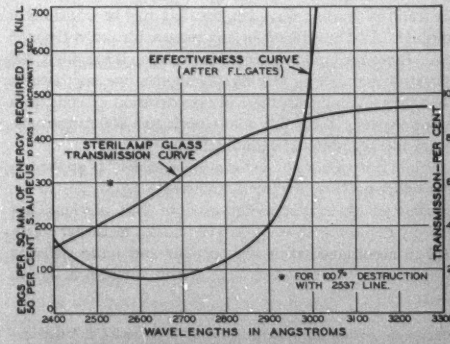

ERGS PER SQ MM OF ENERGY REQUIRED TO KILL 50 PER CENT STAPHYLOCOCCUS AUREUS IN 5 MINUTES AT 37° C
TRANSMISSION—PER CENT
EFFECTIVENESS CURVE (AFTER F.L.GATES)
STERILAMP GLASS TRANSMISSION CURVE
* FOR 100% DESTRUCTION WITH 2537 LINE.
700 600 500 400 300 200 100 0
100 80 60 40 20 0
2400 2500 2600 2700 2800 2900 3000 3100 3200 3300
WAVELENGTHS IN ANGSTROMS

Figure 2. Typical abiotic effectiveness curve of ultraviolet radiation (Gates: report of Rockefeller Institute) and transmission curve of special glass used in Sterilamp tubes

Table I. Characteristics of Some Commercial Ultraviolet Radiators

Over-all lengths, maximum, inches	14½	24½	34½
Effective lengths, inches	10	20	30
Maximum diameter, inches	⅞	⅞	⅞
Lamp shape	Straight tube		
Starting volts, a-c	400	575	750
Operating volts, a-c	275	375	475
Operating current, amperes	0.03–0.05	0.03–0.05	0.03–0.05
Burning position	Any	Any	Any
Effective life	Six months of service		

One of the problems has been to limit the amount of radiations known to react on the atmosphere (oxygen) to produce ozone. This gas in turn may react unfavorably on the membranes of the nasal passages, or have a toxic effect, or may be absorbed by certain materials such as fats and hasten oxidation, or develop objectionable odors and rancidity. It will prevent the transmission of 2,537-Angstrom radiation. Neither are wave lengths much longer than 3,000 Angstroms useful, because such are not as abiotic or would be required in much too great a volume to do the same kind of work as the radiations of shorter wave length.

For the majority of the conceivable applications of short-wave radiation, an excess of energy should be avoided lest the surfaces of nearby objects, especially some food products, might become in a sense cured or "sunburned," or lest the by-product of radiated heat might be objectionable as in air-conditioned or refrigerated spaces. Hence it has been logical to restrict the ultraviolet lamps to a low power consumption, usually about six watts per foot of tubing. Moreover, the small diameter of the arc stream relative to its length, and the carefully chosen mercury-vapor pressure, restricts to a negligible amount the output having wave lengths longer than the strong 2,537-Angstrom band. The commercial lamps normally consume 0.03 to 0.05 ampere, or an average of 35 milliamperes. A 20-inch tube operating at 375 volts thus may consume approximately 12 watts, with the temperature of no part rising more than five to ten degrees centigrade above the ambient temperature. The energy emitted in the visible spectrum is of a pleasant light blue color but negligible for any illumination purposes. At some 18 inches from a typical tube the illumination is no more than one foot-candle.

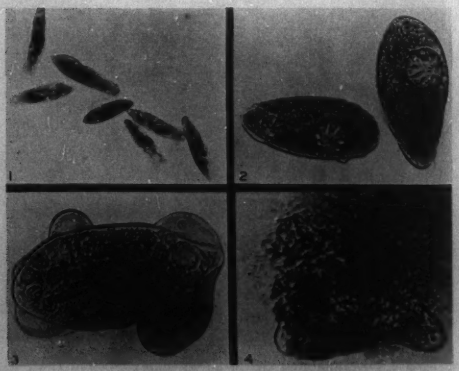


Figure 3. Photomicrographs showing successive phases in the disintegration of paramecia when irradiated

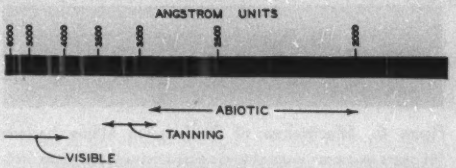


Figure 4. Mercury-arc spectrum showing wave lengths of visible (light) and ultraviolet radiations emitted

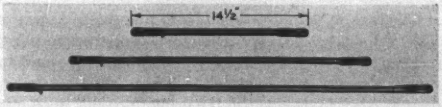


Figure 5. Three common sizes of Sterilamps to produce short-wave radiation

Since the menace of bactericidal infection or the propagation of mold may be continuous, it is expected that in the majority of installations the sterilizing radiation will be made available continuously, or at least during all working hours. In reducing air-borne bacteria in auditoriums, schools, or offices the sterilization process normally would continue during hours of occupancy, in the endeavor to keep the germ count at least as low as would exist outdoors. In the case of food storage as in a refrigerator, the radiation would be advisable 24 hours daily. Such usage has led to the design of commercial lamps for a useful life of the order of 4,000 hours, or six months of continuous burning.

The volume of ultraviolet emission from any particular unit or group of tubes may be controlled by varying the current input through a change of transformer taps, or by the number of tubes in series on one transformer. An uncontrollable influence is that of very cold surrounding air since a condensation of mercury vapor (the pressure approximately 0.4 micron at zero degrees Fahrenheit) normally will reduce ultraviolet output. The vapor pressure is optimum and the radiation is most abiotic when the wall temperature of the lamp is slightly in excess of 45 degrees Fahrenheit. The lamp is designed so that at refrigerated-air temperatures of some 40 degrees Fahrenheit or higher, the output is satisfactory.

As with any gaseous-discharge lamp, these tubes possess negative resistance, requiring a current-limiting device to be used in series. Since the lamp requires a transformer that will deliver a voltage high enough to start the discharge, the current-limiting feature can be incorporated into one unit. From one to four lamps may be operated in series from the secondary of such a transformer, although naturally the current through each tube will vary with the number of tubes. Since the open-circuit second-

Figure 6. Effectiveness of Sterilamp in killing bacteria

The plates have been exposed to the ultraviolet radiation of the Sterilamp for varying lengths of time, then incubated until the remaining bacteria grew into colonies large enough to be photographed as white dots. The durations of exposure, in seconds, were, left to right: 0, $1\frac{1}{4}$, $2\frac{1}{2}$, 5, and 10

ary voltage in a cold-cathode lamp may be in excess of 1,000 volts, it has been advisable to develop deep porcelain sockets to protect the metal ends of the lamps and to supply a power unit in which is incorporated an undercurrent relay to de-energize the primary circuit upon any interruption of the lamp circuit. For stability of operation, the voltage drop across the lamps represents approximately two-thirds of the equivalent supply voltage.

When dealing with extra-short-wave radiations, reflecting and absorbing materials must be chosen critically. Polished or oxidized aluminum is practically the only suitable reflector, with a coefficient of some 60 per cent at 2,600 Angstroms. Chromium is about equally as efficient. Most ordinary glasses are opaque. Some of the fungi or spores can be killed through several inches of clear water, but for bactericidal purposes the penetration in slightly turbid liquids is extremely shallow.

Many months of careful and at times hazardous experimentation with toxic germs and untried wave lengths of energy have evolved an interesting technique that has been predicated upon an exact quantitative measurement of the abiotic radiation. Until recently this measurement has been the missing link. However, when the tantalum photoelectric cell was perfected, this having much the same wave-length response to ultraviolet radiation as the lethal action of these radiations upon bacteria, it became a simple process to tabulate scientifically the abiotic energy necessary to kill any chosen microorganism. Thus in the future sterilizing installations will be planned with an exactness equalling that of the normal lighting installation, and the ultraviolet meter becomes the "brother" of the foot-candle meter.

Numerous circumstances will influence results; but on a comparative basis if 1,000 units of abiotic radiation are required to kill black mold, then to kill other organisms the following ratios exist:

Black mold (Aspergillus niger)	1,000
N. catarrhalis	60–85
B. subtilis	25–30
E. coli	15–20
E. typhosa	7–10

It appears that most of the common bacteria, such as found on the rims of drinking glasses, when reached by direct radiation such as applied by one 30-inch tube at a distance of from three to six inches, will be destroyed in approximately two minutes. Table II gives typical data in the sterilization of drinking glasses (figure 6).

One of the broad fields where sterilizing radiation is applicable is in the preservation of fresh meat (figure 7). Refrigeration, even below 32 degrees Fahrenheit does not kill but merely inhibits the growth of mold and bacteria so that spots of mold and patches of slime caused by putrifying bacteria gradually develop and must be trimmed away before the meat can be sold. Furthermore, the lower the temperature the more difficult it becomes to maintain the humidity in the refrigerator and prevent loss in weight of the meat from dehydration.

It has been found that two 30-inch lamps, consuming a total of less than 25 watts, are sufficient to prevent mold growth and putrefaction in the seven- by nine-foot cooler used by the average retail meat dealer. The temperature can be raised up to but not exceeding 45 degrees Fahrenheit, which usually permits higher relative humidity with less dehydration loss. If the air in the cooler is cir-

Table II. Results of Sterilization Tests on Drinking Glasses

Location	No. of Tests	Before Irradiation: No. of Colonies	After Irradiation, Two Minutes: No. of Colonies	After Irradiation, Two Minutes: Per Cent Improvement
Inside rim	20	2,122	10	99.2
Outside rim	20	4,342	59	99.0
Inside bottom	20	3,492	42	99.0
Inside rim	17	3,600	25	99.0
Outside rim	17	1,732	3	99.3
Inside bottom	17	1,274	18	98.6
Inside rim	15	947	6	99.5
Outside rim	15	631	23	96.3
Inside bottom	15	103	13	87.3

Figure 7. Maintaining sterile air by ultraviolet radiation in a meat storage room; note ultraviolet (U.V.) tubes near ceiling

culated by a fan, no mold or bacterial growths appear even on the surfaces of the meat not directly exposed to the radiation!

The baking industry is another field where the sterilizing lamp has been used with marked success. The room where the dough is held for yeast reaction must be kept warm and moist, conditions likewise favorable for the growth of mold. Although the baked goods are sterilized during the baking, they become recontaminated during the cooling, slicing, and wrapping processes by the mold spores carried by air currents from the dough room. Lamps mounted on the ceiling of the dough room prevent the growth of mold therein, yet since the rays do not penetrate the dough, do not interfere with the yeast reaction. As an added precaution, lamps are mounted in the cooling room or over the cooling conveyors so as to protect the product from contamination until it is wrapped. This technique greatly extends the mold-free life of baked goods.

Air sterilization is perhaps the largest field for ultraviolet radiation. The lamps have been used successfully to reduce the air-borne organisms in hospital operating rooms to prevent infections and in the treatment of contagious diseases to prevent the infection of other patients. It has been found by Rentschler and James of the Westinghouse laboratories that an organism floating in the air is killed with perhaps one-tenth of the radiant energy required to kill that same type of organism once it has settled on an agar plate.

These are but a few of the applications of the sterilizing properties of ultraviolet radiation that have been investigated. Many more constantly are arising, and while no single installation is large, from the standpoint of power consumption, the diversity and universality of the applications suggest that the aggregate load will become a factor for future consideration. There is the further gratification in knowing that through making man's life safer and his economic losses less, the electrical industry is contributing another great benefit to civilization.

Stability Characteristics of Turbine Generators

THIS paper* reviews and analyzes the steady-state stability characteristics of turbine generators taking the effects of saturation into account. The need for such an analysis has become particularly important with the recent trend toward 3,600-rpm units of large capacity. With the development of such units, the designer is forced in the direction of reducing the weight of the rotor per kilovolt-ampere in order to keep the length and diameter within reasonable limits. However, the reduction in weight of the rotor tends to reduce the short-circuit ratio, which has long been used as a measure of the stability characteristics. The determination of the stability characteristics which may reasonably be expected from a machine, and the validity of short-circuit ratio as a criterion for steady-state stability were considered important enough to justify an analysis. Although the paper deals primarily with the cylindrical-rotor type of generator, the results also apply in general to the salient-pole type.

Some of the general conclusions drawn from the results of this study are that a generator without voltage regulator may require a short-circuit ratio of at least 1.0 if it is expected to pick up full load from an initially lightly loaded condition with no change in excitation; that a generator remote electrically from its load should be equipped with a voltage regulator in order that the short-circuit ratio required need not be uneconomically high; and that the reactance of a turbine generator operating at 0.8 power factor overexcited, and provided with a reliable voltage regulator and excitation system, does not influence appreciably the static stability limit, but the limit is influenced considerably by a generator operating at 1.0 power factor near the static stability limit.

Symbolic Analysis of Switching Circuits

IN CONTROL and protective circuits of complex electric systems intricate interconnections of relay contacts and switches frequently are necessary. Examples of such circuits may be found in automatic telephone exchanges, industrial motor-control equipment, and in almost any circuits designed to perform complex operations automatically. In this paper* some of the properties of such networks are analyzed mathematically, and particular attention is given to network synthesis. If the circuit characteristics are given and the circuit incorporating those characteristics is to be found, the solution is not unique, and methods of finding those particular circuits having the minimum number of relay contacts and switch blades are described. Methods for finding any number of circuits equivalent in all operating characteristics to a given circuit also are outlined.

The general method used in this paper is somewhat unusual. Briefly, any circuit is represented by a set of equations, the terms of which correspond to the various relays and switches. The equations then are manipulated by means of simple mathematical processes, most of which are similar to ordinary algebraic algorisms. A special type of calculus is evolved for this use, and is shown to be exactly analogous to the calculus of propositions used in the symbolic study of logic. For synthesizing a circuit the characteristics are first written as a system of equations, then manipulated into the form representing the simplest circuit. From these equations the circuit may be drawn immediately. By this method it is possible always to find the simplest circuit containing only series and parallel connections, and in some instances the simplest circuit containing any type of connection.

* Abstract of 1938 AIEE summer convention paper number 38-98, by C. Concordia (M'37), S. B. Crary (M'37), and J. M. Lyons (A'28), which will be published in full in TRANSACTIONS.

* Abstract of 1938 AIEE summer convention paper number 38-80, "A Symbolic Analysis of Relay and Switching Circuits," by Claude E. Shannon (Enrolled Student), which will be published in full in TRANSACTIONS.

News

Of Institute and Related Activities

Southern District Meeting in Miami, November 28–30

FLORIDA offers extraordinary vacation possibilities to all who plan to attend the Southern District meeting of the AIEE in Miami, November 28–30, 1938. The Miami Biltmore Hotel has been chosen as headquarters because it offers an ideal combination of meeting facilities and recreational advantages, which permits relaxation between business sessions. For those who travel by car, many points of historical and scenic interest will be available en route. For those who come direct by rail, both organized side trips and individual trips by special parties will be available. Miami and Florida have many things that will both interest and amuse visitors.

Sports

At the disposal of members and guests at the headquarters hotel are all the equipment and grounds of the famous Miami Biltmore Hotel. Located on the grounds are fast championship tennis courts and a large outdoor swimming pool renowned for aquatic records which have been broken in its waters and from its diving boards. Also, on the grounds for use in the intervals between committee meetings and gatherings, are the 6,640-yard, 18-hole championship golf course upon which the Miami Biltmore open tournament is played each year, with its beautiful club house, and a bridle path for those who enjoy horseback riding.

Headquarters hotel guests also have the extraordinary privileges of the Florida year-round clubs. Those staying at the Miami Biltmore are granted temporary membership in these three sports clubs. First, there is the Miami Biltmore Country Club, adjoining the hotel, with a sporty, championship golf course and one of the most beautiful club houses in the country, with professional instructors. Second is the famous Roney Plaza Cabana Sun Club, Miami Beach, with a private beach, outdoor salt-water pool, lockers, tennis courts, tropic gardens, sun-bathing facilities, sidewalk cafe and an outdoor terrazzo dance floor in a grove of coconut palms. And third, there is the Key Largo Anglers Club, 48 miles south of Miami, on one of Florida's tropical "keys"—an island for informal living and sport-fishing.

Important to your personal budget is the unusual economy provided by the Miami Biltmore's fleet of "aerocars" which transport guests to all resort activities in this area without charge. These "aerocars," moving on rapid schedules, ply between the Miami Biltmore and Miami Beach, traversing the business and theater districts of Coral Gables, Miami, and Miami Beach, to and from Key Largo and intermediate interests southward.

Entertainment

Group luncheons are planned for members and guests on Monday and Tuesday. A banquet for students and members will be held Monday night, at which time student paper awards will be made. There will be a formal banquet Tuesday evening for all members, guests, and their families. In addition to the entertainment furnished to the women by the various sports, sightseeing and bridge have been arranged for their entertainment during the technical sessions. All should take their golf clubs, bathing suits, tennis rackets, or riding habits so that favorite pastimes can be enjoyed to the fullest extent.

Technical Sessions

Including the student session, four technical sessions will comprise the program. Monday morning will be devoted to registration and opening of the meeting followed by a lecture "Measuring Electrically." The afternoon session will be devoted entirely to student activities. Technical sessions Tuesday and Wednesday mornings will deal with transmission, distribution, generation, and related problems, while Tuesday afternoon will be devoted to papers and discussions of education, economic, and sociological subjects.

Side Trips

Arrangements have been made for two- and four-day trips to Havana at nominal expense for those who would enjoy a trip to the Cuban capital after the meeting.

A trip to Key West over the recently completed Overseas Highway, and inspection of the Nine-Mile Bridge and Bahia Honda Bridge, unique in their engineering and structural features, will prove interesting to many guests. Built upon the right-of-way and trestles of the Florida East Coast Railway to Key West, which was so damaged in the 1935 hurricane that it no longer was used for rail travel, this highway traverses a route over tropical, colorful waters, and provides an unusual and interesting journey not to be found in other highway travel.

Arrangements also have been made for a trip from Miami to the sugar mill and farms of the U.S. Sugar Company in Clewiston. Guests who avail themselves of this trip not only will have an opportunity to view the sugar production industry, but will pass through the rich Everglades muck land section, in which much of the winter vegetable crop is produced, and may inspect the $20,000,000 Lake Okeechobee dyke system which was completed in 1937. This dyke, 200 feet wide at the base and 20 feet at the crest, extending around approximately three-fourths of Lake Okeechobee, together with

Miami Biltmore Hotel from golf course

its system of locks and drainage gates, was constructed to prevent repetition of the enormous destruction of life and property which accompanied a hurricane over Lake Okeechobee in 1928.

Sightseeing trips over Miami, Miami Beach, Coral Gables, and all points of interest in the Miami area have been arranged, and each guest will have ample opportunity to become acquainted with the beauty of Miami.

Rules on Presenting and Discussing Papers

Papers presented at technical sessions may be presented in abstract, presentation not to exceed ten minutes unless otherwise arranged, or the presiding officer may meet with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion.

Any member is free to discuss any paper when the meeting is opened for general discussion. Ten minutes for prepared discussion and ten minutes for open discussion will be allowed on each paper. Those presenting written discussions will be selected from the various Sections in the Southern District. Open discussions are invited and all members should feel free to enter into them.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser should step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussions prepared in advance should be left with the presiding officer.

Other discussions to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th Street, New York, N. Y., on or before December 14, 1938.

Hotels and Registration

Hotel rates, including all privileges of Florida year-round clubs will be: single, $3.50 to $5; double $6 to $8. Meals at the hotel will be served at: breakfast 50¢ to $1; luncheon 75¢ to $1.25; dinner $1.25 to $2. Special rates for students have been obtained at the Casa Loma Hotel, adjacent to the headquarters hotel at $1 per day with meals at $1.70 a day up. Students in the Casa Loma Hotel will have privileges of the swimming pool. Reservations should be made as soon as is practical by addressing the Miami Biltmore Hotel, convention department, Coral Gables, Fla.

Members who will attend the meeting and who have not already registered in advance are urged to do so promptly. This will be helpful to the committees and will permit badges to be made ready in advance, thus avoiding congestion at the registration desk. Please complete the registration promptly upon arrival at the meeting.

No registration fee will be charged members or their immediate families or Enrolled Students, but a registration fee of $2 will be charged all nonmembers. Tickets for entertainment features will be available at the registration desk and all members and guests are urged to procure these tickets at the time of registration.

Committees

The personnel of the Southern District meeting committee is as follows: A. P. Michaels, *chairman;* E. D. Wood, vice-president, AIEE Southern District; A. S. Hoefflin, secretary, AIEE Southern District; E. E. George; E. F. Johnson; M. E. Lake; E. F. Smith; W. Austin Smith; and Joseph Weil. The chairmen of the subcommittees are as follows: J. Coleman Jones, *program;* J. B. Hiers, Jr., *finance;* J. D. Preston, *attendance and publicity;* P. J. Carlin, *transportation and inspection trips;* R. Y. Pool, *entertainment;* E. F. Johnson, *hotel and reservations;* and E. F. Smith *student activity;* W. Austin Smith, *papers;* and H. V. Street, *registration.*

Program

Photo-offset copies of authors' manuscripts, exclusive of addresses, may be obtained in advance of the meeting by writing to the AIEE Order Department, 33 West 39th Street, New York, N. Y. Only numbered papers will be available in advance-copy form. If ordered by mail, price 10¢ per copy; if purchased at Institute headquarters or at the meeting, price 5¢ per copy. Coupon books in $1 and $5 denominations are available for those who wish to avoid remittance by check or otherwise. Some of the papers ultimately will be published in ELECTRICAL ENGINEERING or the TRANSACTIONS.

Monday, November 28

Opening Session

8:30 a.m.—Registration
10:00 a.m.—Address of welcome
10:15 a.m.—Response and announcements
10:30 a.m.—Illustrated lecture: MEASURING ELECTRICALLY, **Everett S. Lee,** General Electric Company

12:30 p.m.—Group luncheons

2:00 p.m.—Student session

7:30 p.m.—Students' and counselors' banquet and student paper awards

Tuesday, November 29

9:00 a.m.—Technical Session

120. RURAL LINE PROTECTION UTILIZING COORDINATED RURAL PROTECTIVE DEVICES, **W. H. Rollman** and **F. J. Guice,** Memphis Power and Light Company.

121. ELECTROLYSIS AND CORROSION OF UNDERGROUND METALLIC STRUCTURES, **R. J. Kuhn,** consulting engineer, New Orleans, La.

122. LOADING TRANSFORMERS BY COPPER TEMPERATURE, **H. V. Putman** and **W. M. Dann,** Westinghouse Electric and Manufacturing Company.

123. LIGHTNING PROTECTION IMPROVEMENTS FOR TRANSMISSION LINES, **Llewellyn Evans,** Tennessee Valley Authority.

12:30 p.m.—General assembly luncheon

2:00 p.m.—Technical session

124. GRADING THE ENGINEER'S JOB, **R. H. Kirkwood,** Tennessee Valley Authority.

Address: MODERN ASPECTS OF ENGINEERING EDUCATION, **Joseph Weil,** University of Florida.

Address: THE SOUTHERN ENGINEER WEIGHS NEW PROBLEMS OF NEW INDUSTRY, **Eugene O'Brien,** *Southern Power Journal.*

Address: THE BUSINESS MAN LOOKS ON THE ENGINEERING GRADUATE, **Kendall Weiseger,** Southern Bell Telephone and Telegraph Company.

8:00 p.m.—Banquet and dance

Wednesday, November 30

9:00 a.m.—Technical Session

125. ELECTRICAL DESIGN OF PICKWICK LANDING PROJECT, **E. P. Almond,** Tennessee Valley Authority.

126. THE MULSIFYRE SYSTEM FOR EXTINGUISHING OIL FIRES, **K. P. Jones,** Grinnell Corporation.

127. RECONDITIONING OF INSULATING OILS BY ACTIVATED ALUMINA, **J. E. Housley,** Aluminum Company of America.

128. SHOP PRACTISE IN THE REPAIR OF HIGH-VOLTAGE BUSHINGS, **G. F. Stratton** and **W. L. Stratton,** Armature Winding Company.

129. GENERATOR DAMPER WINDINGS AT WILSON DAM, **R. B. George** and **B. B. Bessesen,** Tennessee Valley Authority.

Treasurer Slichter Visiting South America

W. I. Slichter (A'00, F'12), head of the department of electrical engineering at Columbia University and national treasurer of the Institute, left New York, October 22, on an extended tour during which he will visit the principal coastal cities of South America and will skirt the entire continent before returning to the United States in January 1939. Treasurer Slichter expects to pay a visit to F. M. Servos (A'19, M'27), AIEE local honorary secretary for Brazil, during a stay of two weeks in Rio de Janeiro and São Paulo. He will attempt to see as many South American members of the Institute as possible, particularly in the Brazilian cities, and in Buenos Aires (Argentina), Santiago (Chile), and Lima (Peru). In each of these cities Professor Slichter expects to stay a week or more.

Annual Power Exposition. The Thirteenth National Exposition of Power and Mechanical Engineering, to be held at Grand Central Palace, New York, N. Y., December 5–10, 1938, is said to have attracted many exhibitors, and, according to the managers of the exposition, anticipation of improvement in business activity has stimulated manufacturers to increased interest in the exposition.

Nomination of AIEE Officers for 1939 Election; Members' Suggestions Invited Until December 15

FOR the nomination of national officers to be voted upon in the spring of 1939, the AIEE national nominating committee will meet during the winter convention, January 23–27, 1939. The officers to be elected are: a president, a national treasurer, three directors, and five vice-presidents, one from each of the even-numbered geographical Districts. Fellows only are eligible for the office of president, and Members and Fellows for the offices of vice-president, director, and national treasurer.

To guide this committee in performing its constituted task, suggestions from the membership are, of course, highly desirable. To be available for the consideration of the committee, all such suggestions must be received by the secretary of the committee at Institute headquarters, not later than December 15, 1938.

In accordance with the provisions in the constitution and by-laws, as amended during 1935 and quoted in the following paragraphs, actions relative to the organization of the national nominating committee are now under way.

Constitution

28. There shall be constituted each year a national nominating committee consisting of one representative of each geographical district, elected by its executive committee, and other members chosen by and from the board of directors not exceeding in number the number of geographical districts; all to be selected when and as provided in the by-laws. The national secretary of the Institute shall be the secretary of the national nominating committee, without voting power.

29. The executive committee of each geographical district shall act as a nominating committee of the candidate for election as vice-president of that district, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The national nominating committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The national nominating committee shall name on or before January 31 of each year, one or more candidates for president, national treasurer, and the proper number of directors, and shall include in its ticket such candidates for vice-presidents as have been named by the nominating committees of the respective geographical districts, if received by the national nominating committee when and as provided in the by-laws; otherwise the national nominating committee shall nominate one or more candidates for vice-president(s) from the district(s) concerned.

By-Laws

SEC. 22. During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district that by December 15 of that year the executive committee of each district must select a member of that district to serve as a member of the national nominating committee and shall, by December 15, notify the secretary of the national nominating committee of the name of the member selected.

During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district in which there is or will be during the year a vacancy in the office of vice-president, that by December 15 of that year a nomination for a vice-president from that district, made by the district executive committee, must be in the hands of the secretary of the national nominating committee.

Between October 1 and December 15 of each year, the board of directors shall choose 5 of its members to serve on the national nominating committee and shall notify the secretary of that committee of the names so selected, and shall also notify the 5 members selected.

The secretary of the national nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the national nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the national nominating committee shall be published in the March issue of ELECTRICAL ENGINEERING (Journal of AIEE), or otherwise mailed to the Institute membership not later than the first week in March.

Future AIEE Meetings

Southern District Meeting
Miami, Fla., November 28–30, 1938

Winter Convention
New York, N. Y., January 23–27, 1939

South West District Meeting
Houston, Texas, Spring, 1939

North Eastern District Meeting
Springfield, Mass., May 1939

Summer and Pacific Coast Convention (combined)
San Francisco, Calif., June 26–30, 1939

Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Great Lakes District Meeting
Minneapolis, Minn., Fall, 1939

INDEPENDENT NOMINATIONS

Independent nominations may be made in accordance with provisions in Section 31 of the constitution and Section 23 of the by-laws, which are quoted below:

Constitution

31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the by-laws; such petitions for the nomination of vice-presidents shall be signed only by members within the district concerned.

By-Laws

SEC. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (constitution), must be received by the secretary of the national nominating committee not later than March 25th of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) H. H. HENLINE,
November 1, 1938 *National Secretary*

Chemical Industry Awards. W. S. Landis, of the American Cyanimid Company, New York, N. Y., has been elected to receive the Perkin Medal of the Society of Chemical Industry for 1939. The medal is awarded annually for valuable work in applied chemistry, and will be presented this year to Doctor Landis for his work on cyanimid, derivatives of cyanimid, fertilizers, the first commercial production of argon, and contributions to the explosives industry. The medal will be presented at a meeting of the Society on January 6, 1939. The Chemical Industry Medal of the Society was presented to J. V. N. Dorr, of The Dorr Company, New York, N. Y., at a joint meeting with the American Chemical Society, November 4, 1938, in New York, "in recognition of his inventions and subsequent world-wide introduction of apparatus and processes in many chemical, metallurgical, and sanitational operations which have made possible low-cost production on a large scale."

Additional Committee Personnel Announced

A complete list of the Institute's officers and committees for the year 1938–39 was published in the September 1938 issue of Electrical Engineering, pages 397–99, with the exception of the technical committees on industrial power applications, transportation, and power generation. Announcement of the membership of these committees was made recently, and is presented here.

The listing of the committees is arranged in the same typographical style as the lists in the September issue, so that all who so desire may complete the previous lists by cutting out the following and pasting them in the appropriate spaces.

Industrial Power Applications

J. D. Wright, Chm., General Electric Company, Schenectady, N. Y.

E. A. Armstrong	M. J. McHenry
R. F. Chamberlain	F. C. Nicholson
C. W. Drake	J. J. Orr
John H. Edwards	William A. Perry
E. Gordon Fox	D. E. Renshaw
F. E. Harrell	H. W. Rogers
L. C. Ilsley	F. O. Schnure
R. L. Kingsland	L. A. Umansky
A. E. Knowlton	R. L. Walsh
Carl Lee R. H. Wright	C. J. White

Power Generation

E. C. M. Stahl, Chm., Consolidated Edison Company of New York, Inc., 4 Irving Place, New York, N. Y.

H. C. Albrecht	S. J. Lisberger
F. A. Annett	C. E. Magnusson
G. M. Armbrust	A. C. Monteith
W. L. Cisler	E. F. Pearson
C. A. Corney	G. G. Post
H. M. Cushing	C. R. Reid
J. H. Foote	A. E. Silver
R. L. Frisby	Philip Sporn
W. D. Hardaway	Robert Treat
N. B. Hinson	Sidney Withington
J. W. Lingary	Edwin D. Wood

Transportation

W. S. H. Hamilton, Chm., New York Central System, 466 Lexington Avenue, New York, N. Y.

R. Beeuwkes	Fraser Jeffrey
G. E. Bishop	L. C. Josepha
John C. Davidson	R. L. Kimball
C. M. Davis	A. J. Klatte
E. G. Davis	F. C. Lindvall
J. V. B. Duer	P. A. McGee
D. D. Ewing	R. J. Needham
E. B. Fitzgerald	J. A. Noertker
J. E. Gardner	F. B. Powers
Selby Haar	W. I. Slichter
P. H. Hatch	Dwight L. Smith
G. L. Hoard W. M. Vandersluis	L. J. Turley

Delegates to IEC Meeting

THREE of the delegates who attended the ninth plenary meeting of the International Electrotechnical Commission held recently at Torquay, England (*EE Oct. '38, p. 424*); left to right: P. L. Alger (A'17, F'30) United States delegate, General Electric Company, Schenectady, N. Y.; K. E. G. Eriksson (A'13) Swedish delegate, Allmanna Svenska Elektriska Aktiebolaget, Ludvika; C. H. Sharp (A'02, F'12) president, United States National Committee, IEC.

Plans Already Initiated for 1939 Summer Convention

Plans for the AIEE 1939 combined summer and Pacific Coast convention to be held in San Francisco, Calif., June 23–29, are progressing actively under the leadership of S. J. Lisberger, general convention chairman, according to J. S. Moulton, publicity subcommittee chairman. The convention committee and its several subcommittees are hard at work on their plans and give assurance of an outstanding convention.

Every endeavor is being made to present a well-rounded program of technical papers which will appeal to all groups within the industry. The dual magnets of the Golden Gate International Exposition and the scenic attractions of the Pacific Coast are being counted upon as additional attractions to produce a large attendance.

The personnel of the convention committee is as follows: S. J. Lisberger, *chairman;* D. I. Cone, *vice-chairman;* G. C. Tenney, *secretary;* R. O. Brosemer, *treasurer.* Subcommittee chairman: M. S. Barnes, *registration;* R. J. Cobban, *sports;* A. W. Copley, *reception;* E. A. Crellin, *hotel;* F. R. George, *trips and local transportation;* J. S. Moulton, *publicity;* Stanley Rapp, *transportation;* H. H. Skilling, *student activities;* W. C. Smith, *program.*

Transactions "Supplement" to Be Issued in December

As announced in the October issue and in a special brochure mailed to all AIEE members, a special TRANSACTIONS "Supplement" will be published by the Institute in December. To eliminate a point of confusion that has arisen, this "Supplement" is not a supplement to the annual TRANSACTIONS volume, but is being published for the benefit of those who have not subscribed to the TRANSACTIONS. Under the present publication policy, some of the Institute's technical papers and discussions are not published in the TRANSACTIONS section of ELECTRICAL ENGINEERING, but appear only in the bound TRANSACTIONS volume; the "Supplement" is a reprint of these papers and discussions. Thus, a member who did not subscribe to the 1938 TRANSACTIONS still can obtain all the technical material published by the Institute during the year by "supplementing" the material he received month by month in the TRANSACTIONS section of ELECTRICAL ENGINEERING with a copy of the TRANSACTIONS "Supplement."

Normally under the present publication policy, the TRANSACTIONS Supplement would contain approximately 350 pages, and the price to members would be $1.00 per copy postpaid. Because of the effects of this year's transition in publication procedure, however, the 1938 Supplement will contain only some 85 pages and will be available to members at 50c per copy postpaid. The Supplement will be paper bound similar to ELECTRICAL ENGINEERING.

Advance orders are required because the number of copies to be printed will be determined by the demand. As the Supplement will be reprinted from the TRANSACTIONS early in December, those wishing to receive copies should place their orders with Institute headquarters immediately.

A convenient order form may be found on page 16 of the advertising section of this issue.

Future Meetings of Other Societies

American Association for the Advancement of Science. Winter meeting, December 27–31, Richmond, Va.

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 13–16, New York, N. Y.

American Physical Society. 223d meeting, November 25–26, Chicago, Ill.

224th meeting, December, Los Angeles, Calif.

Annual meeting, December 26–28, Washington, D. C.

American Society of Civil Engineers. Annual meeting, January 18–20, New York, N. Y.

American Society of Heating and Ventilating Engineers. Annual meeting, January 23–26, Pittsburgh, Pa.

American Society of Mechanical Engineers. Annual meeting, December 5–9, New York, N. Y.

Spring meeting, February 23–25, New Orleans, La.

American Society of Refrigerating Engineers. Annual meeting, December 6–8, New York, N. Y.

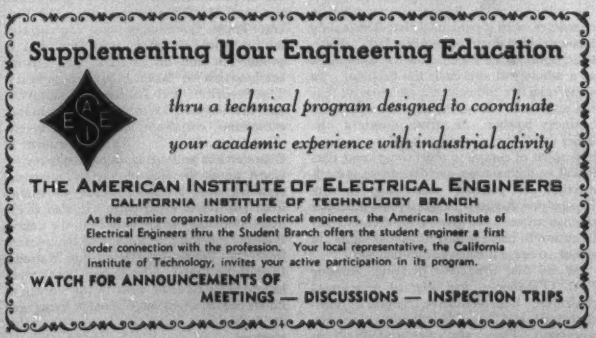
National Research Council, Highway Research Board. Annual meeting, November 20–December 2, Washington, D. C.

Society of Automotive Engineers. National transportation engineering meeting, November 14–16, New York, N. Y.

Annual meeting, January 9–13, Detroit, Mich.

Society of Naval Architects. Annual meeting, December 1–2, 1938, New York, N. Y.

Promotional Blotter Distributed by AIEE Branch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WATCH FOR ANNOUNCEMENTS OF
MEETINGS — DISCUSSIONS — INSPECTION TRIPS

TO STIMULATE interest in the work of the AIEE Branch at the California Institute of Technology, Pasadena, officers of the Branch distributed promotional blotters among electrical-engineering students at that institution, imprinted as shown above. The blotter was evolved by S. G. Schneider, secretary of the Branch.

17-Year AIEE Index May Be Issued Soon

As announced in the October issue and in a special brochure mailed to all AIEE members, the issuance of a cumulative index to AIEE technical papers published during the 17-year period, 1922–38, is under consideration. Such a volume would complete the series of indexes covering Institute papers from 1884 to date, but will be issued only if there is sufficient demand for it. Orders are coming in daily, and indications are

that enough will be received ultimately to enable the index to be published at an acceptable price. Since the number to be printed, and consequently the price, will be determined by the number of orders received, it is doubly important that orders be placed promptly.

Covering some 2,500 reports and technical papers by several hundred authors and technical committees, the proposed index would comprise a volume of 150 or more 8½- by 11-inch pages containing some 15,000 reference entries alphabetically arranged. The style and arrangement of the index would be similar to the annual multi-entry indexes that have been published during recent years for TRANSACTIONS and ELECTRICAL ENGINEERING. As an added inducement, it is planned that a copy of the previous index volume, covering the years 1911–21, will be given free of charge to those ordering copies of the new index, until the present stock is exhausted.

The price of the proposed 17-year index to AIEE members will range from $1.25 upward, depending upon the quantity to be produced, but will be kept to a minimum. Those interested are urged to place their orders with Institute headquarters immediately.

A convenient form may be found on page 16 of the advertising section of this issue.

Current Items From American Engineering Council

AEC Staff Analyzes the Government Inquiry Into Monopoly

An AEC staff analysis of the history and present status of the monopoly inquiry which may provide a basis for new Federal legislation on wages, prices, patents, and other fundamental economic industrial questions

THE prolonged depression with its "recessions" has accentuated the waxing problem facing the administration of how and by what means our economic mechanism may be made to function in such a way as to bring about real recovery in business conditions. This has brought to the fore the need of an inquiry into the possible causes preventing such recovery.

This resulted in the passage of the joint resolution (S.J.300) by Congress establishing a Temporary National Economic Committee to make such inquiry. The inquiry is to be an antimonopoly inquiry. There is the feeling that in due time this "temporary" committee will develop into a permanent committee or some such body.

The establishment of the National Economic Committee to make an antimonopoly investigation is no new thing in our economic and political history. Every business depression led to such investigation and was followed by legislation and the creation of a permanent body to deal with various aspects of the monopoly problem. With this established historical precedent the creation of the antimonopoly inquiry was an inevitable procedure, and the passage of legislation to further regular business is sure to follow. What the nature of the act will be is of course difficult to forecast.

COMPOSITION OF THE COMMITTEE

The committee is composed of 12 members as follows: (1) three members from the Senate appointed by the president; (2) three members from the House of Representatives; and (3) one representative from each of the following departments: Department of Justice, Department of the Treasury, Department of Labor, Department of Commerce, Securities and Exchange Commission, and the Federal Trade Commission.

The three Senators appointed are: O'Mahoney, Borah, and King; the three representatives: Sumners, Eicher, and Reece; the six executive agency members; Thurman Arnold, assistant attorney general, Hon. O. Douglas, chairman of the Securities and Exchange Commission, Herman Oliphant of the Treasury Department, Garland Ferguson, chairman of the Federal Trade Commission, R. C. Patterson, assistant secretary, Department of Commerce, and Isador Lubin, chief of Bureau of Labor Statistics.

Thus, from the point of view of structure, the committee is legislative-executive in character, with a personnel that dominately has a decided antimonopolistic bias. However, opinions vary as to how the committee as a whole will approach the problem. In some quarters impressions are current that the approach will be through the avenue of business baiting. In other quarters, the belief exists that the inquiry will be pursued in a spirit of complete objectivity, and that it will be nonpartisan and free from any admixture of politics. According to the *Washington Review*, "legislative members of the committee have given assurance of their intention to make a fair, impartial study, so as not to cause business apprehension."

At its first executive meeting, Senator J. C. O'Mahoney was selected permanent chairman, Representative Sumners, vice-chairman, and Leon Henderson, executive secretary. There also was appointed an executive committee consisting of Senator O'Mahoney, Representative Sumners, Thurman Arnold, Richard Patterson, and Isador Lubin, to function while the general committee is not in session. The executive office of the committee is in Room 218 of the Federal Trade Commission Building.

Since the establishment of the committee, its executive members have taken the initiative in leadership. Several private conferences, usually under the guidance of W. O. Douglas, chairman of the Securities Exchange Commission, were held. Among those who participated at these conferences were: Robert Jackson and Thurman Arnold, No. 1 and No. 2 trust-busters; Jerome Frank, author of "Law and the Modern Mind," and "Save America First"; Herman Oliphant, treasury official, author of the Undistributed Profit Tax; Isador Lubin, labor statistics; and Leon Henderson, former WPA economist.

An informal conference, at which ten leading business men attended, met with Richard Patterson of the Department of Commerce. Among them were: E. R. Stettinius, chairman of the board of the United States Steel Corporation; W. A. Harriman, chairman of the board of the Union Pacific Railroad; Clarence Francis, president of the General Foods Corporation; and S. Clay Williams of the Reynolds Tobacco Company.

PLAN OF WORK

The present plan of work for the committee is to call upon the proper government agency for a specific study of certain aspects of a particular industry or business. Meanwhile, groundwork is being laid by each of the six agencies represented on the committee to make ready certain accumulated information on various business enterprises, which indicate monopolistic policies and practices. The extent to which such practices affect the proper working of the price structure of our economic mechanism, causing what economists call an unbalanced price structure, will be carefully analyzed.

The committee met on July 7 and outlined a general scheme of approach to the study designating the different departmental objectives. Since then, much preliminary work has been undertaken. The Department of Justice has investigated industrial combinations and their price policies and will make available pertinent data which it has accumulated in the investigation and prosecution of antitrust cases. The Federal Trade Commission has concentrated on problems of unfair trade practices in production and distribution, and existing combination in business and in industry. The Securities and Exchange Commission has investigated investments of insurance companies, corporate finance, and investment banking credit. The Department of Commerce is presenting an economic review based upon the size of various industrial organizations, a report based on studies from the NRA experience. It also would make available certain data from the Census Bureau, the Patent Office, and the research from the Trade Association and National Income Sections. The Labor Department has co-ordinated the data in the Bureau of Labor Statistics on wages, cost of living, and unemployment, with the data of the other agencies.

The Bureau of Labor Statistics representing the Department of Labor also is preparing charts that will show up these industries in which prices have been steady or fairly steady over a period of time. This

chart is superimposed on charts showing the nature of steadiness or irregularity in various industries and will show the relations between these three factors. These charts will indicate the points at which the economic system begin to endanger steady employment and income. The department then will turn to other agencies such as the Federal Trade Commission for a further and detailed study of the problem. The Treasury Department has concentrated on matters of taxes and will present data relevant to "tax escape devices," and also data on bids for government contracts which may indicate concerted efforts on the parts of manufacturers to maintain identical prices for their products.

Scope of Investigation

Careful analysis of the issues involved in this "full and complete study" makes it clear that the investigation is to be more than merely antimonopoly. It is to be a broad and all inclusive study of any and all parts of our economic structure, the nature of their interrelationship, and the manner in which they function in American present-day economy. Thus the study will extend into a careful and detailed scrutiny of virtually every aspect of management and administration policies of every great enterprise in the country. It will cover everything touching the form, structure, and function of every large business organization. As one of the men of the committee remarked: "This is the most important investigation ever to be made of the economic life of the most important nation in the world."

To allay apprehension on the part of business and industry, members of the committee give assurance that politics will not enter as a factor in influencing the formation of their opinions and conclusions. Factual data alone, it is stated, will serve as a basis for recommendations to Congress and president as to the best and most feasible guide policy of control and regulation of business practices within the framework of our existing economy.

Outcome of Investigation

There is a natural undercurrent of anxiety on the part of industrialists, as to what will be the outcome of this investigation. Prognostications are, at present, premature and hazardous. Examination of the basic theoretical principles, enunciated by some members of the committee in their writings, brings to light two possible recommendations for governmental policy. One is the break-up of monopoly and corporate concentration, so as to bring about the existence of a free competitive market; the other is the further increase of governmental control and "a shift in the manner of administered prices." These principles are also clearly enunciated by President Roosevelt in his April message to Congress, asking for the investigation. He says: "The power of a few to manage the economic life of the nation must be diffused among the many or be transferred to the public and its democratically responsible government. If prices are to be managed and administered, if the nation's business is to be allotted by plan and not by competition, that power should not be vested in any private group or cartel, however benevolent its professions profess to be." The president is further on record in favor of amendments to the antitrust laws that would set down specific standards and then would place upon the corporation the responsibility of proving that it had not violated those standards, if evidence is produced to the contrary. In other words, a corporation would be expected to be prepared to prove that it had not engaged in practices tending to restrain competition.

The "Berle Memorandum"

One of the contributions made to the committee investigating monopoly is contained in the so-called "Berle Memorandum" prepared by A. A. Berle, Jr., one of the economic advisers to the administration. Its criticisms of the undistributed profit tax, of the proposed federal incorporation and licensing laws, of the "imposed shotgun regulation of the New Deal" has gained extra circulation, if not weight, because the author has been an adviser of administrative policies for several years.

The significance of the Berle Memorandum is that it gives business men and financiers a hint of the nature and scope of the investigation that is to be made. It is an outline of a partial analysis of existing business organizations and of the business practices in the country, suggesting methods of controlling our business system so that it will work. The objectives of the investigation are set forth clearly in the introductory statement: "The investigation of business organization and practices should be essentially a search to find an organization of business that actually works."

Three tests of the success of business organization are recommended. These include the provision for: (1) more goods, better quality of goods, and lower prices of goods; (2) more jobs, better paying jobs, and steadier jobs; (3) the accomplishment of this process must be with due regard for the liberty and self-development of the individual. Any plan for control should have these criteria as its main objective, else it means very little.

For purpose of better clearness and understanding, we believe it is best perhaps to quote a statement of the summary verbatim.

"First, the general scope of the investigation ought to be a search for an organization of business that actually works;

"Second, the standard must be whether it supplies the existing and developing wants of the people as they appear;

"Third, that this involves the provision of an adequate supply of goods;

"Fourth, and a distribution system that takes these goods toward known wants to the maximum degree possible;

"Fifth, that the system must provide a maximum number of people with means of satisfying those wants through a contribution to the system;

"Sixth, that the system must provide the people engaged in the process with a manner of life, which at least tends to satisfy a fair proportion of their wants;

"Seventh, the system must evolve a method of organization that does not interfere unduly actually or potentially, with the liberty of the individual; i.e., that its controls must release more individuality than they suppress;

"Eighth, that there is no need to assume that these tests will be met by any single system or any single standard of size or set of practices at any given point."

Copies of the memorandum are available from AEC headquarters, 744 Jackson Place, Washington, D. C.

Seventh International Management Congress

Sponsored by some 20 national technical, economic, statistical, and business organizations, of which American Engineering Council was one, the Seventh International Management Congress held in Washington, D. C., September 19–24, brought together a remarkable group of leaders of industry and management, not only from the United States and Canada but from 20 additional nations. The paid registration was approximately 1,500.

William L. Batt, president of SKF Industries, past-president of the American Society of Mechanical Engineers and member of the AEC executive committee, was elected president of the International Committee of Scientific Management, and Sweden was chosen as the place of meeting for the Eighth International Management Congress to be held in 1941. Mr. Batt succeeded Viscount Leverhulme of London as president. The congress was opened with a message from the Honorable Cordell Hull, Secretary of State, delivered by Undersecretary Messersmith, because of the pressure of world events.

Management's New Responsibilities

The program of the congress was divided into two sections with over 200 papers presented in abstract by special rapporteurs, at six parallel technical sessions. This division of the program had in general the theme of improvement of techniques of management in administration, personnel, production, distribution, agriculture, and the home. The second part of the program had as its theme the responsibilities of management as the functioning group in industry and trade which has the task of writing the objectives of labor and capital for the common good of both these factors and the public.

Management's responsibilities were clearly shown to have entered the professional field due to the advanced scientific methods of production. It was pointed out that to provide social security, there must be a reorientation of business to the great economic and social forces which now surround and control their own activities. That management must be conducted along the lines that would develop mutuality of interest of the executive and the workers. This new concept must be foremost among the aims of enlightened industrial management.

Closely akin to the responsibilities emphasized in the management and industry relationship were those of management and labor, the problems of which must be settled outside of party politics. The technological progress within recent years also has created new problems which management must face and solve wisely.

Desirable social developments can be realized only through the action of two forces: better technical developments, and better management. The greatest management problem is that of determining the most advantageous balance between the two prin-

ciples of decent group life and properly oriented operation. Management no longer represents a single interest, but rather it functions on the basis of a trusteeship, endeavoring to maintain a proper balance of equity between the shareholder, the jobholder, the customer, and the public in general.

A Note of History

L. P. Alford called attention to the fact that the organization of the Seventh International Management Congress was one of the indirect products of the inquiry into waste in industry, undertaken by AEC in 1920–21. At that time, the newly organized Czechoslovakian Government was searching for ideas for the development of industry and the published report of Council on "Waste in Industry" came to the attention of Doctor Stepanek, the Czechoslovakian minister to the United States. He, with Doctor Spacek, the technical attaché of the legation, called on Council and asked whether a way might be found to call a conference in Czechoslovakia that would enable the government to take advantage of the recommendations of the report on "Waste in Industry" in his own country. As a result of this inquiry, representatives of AEC and its member organizations developed a special committee which, in co-operation with the Czechoslovakian Government and the Department of State of the United States, arranged for the organization of the First International Management Congress held in Prague in 1924.

So much interest was aroused at this congress, that a number of the nations represented proposed that other nations organize committees of scientific management and that a second congress be held having as its basis international co-operation in widening the understanding of scientific management principles. In consequence, the second congress was held in Brussels in 1925 and there followed in order, congresses in Rome 1927, Paris 1929, Amsterdam 1932, London 1935, and the Seventh Congress just closed, held in Washington in 1938.

Participation of AEC

It was natural, therefore, that representatives of AEC should take an active part in the organization and in the deliberations of the Seventh International Congress. Many members of the official family of Council participated in presenting papers and discussions.

The executive secretary of AEC, at the request of the co-ordinating committee headed by W. L. Batt, acted as liaison secretary for the congress in all Washington matters including general arrangements for the meetings, relationships with State, War and Navy, Commerce, and other government departments, the social events and the program for the general sessions. Some 20 members of the staff of the United States Bureau of Foreign and Domestic Commerce were assigned to him by the secretary of Commerce and the director to assist in managing the meetings, and the staff of the Chamber of Commerce of the United States co-operated in perfecting the physical arrangements for the meeting under the direction of the president and the secretary of the chamber.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. Electrical Engineering will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Critical Conditions in Ferroresonance

To the Editor:

The list of references given at the end of the paper by P. H. Odessey and E. Weber on resonance with iron-cored inductances [*EE, Trans. Sect., Aug. '38, p. 444*] contains no articles in the English language earlier than 1931. However, this phenomenon was independently observed, and described by the writer and C. W. Baker in 1911 in the article "Double Voltages in Circuits having Capacity and Inductance," in *The Electric Journal*, 1911, volume 8, page 1102. At that time, as in several later instances, the phenomenon was dangerous and harmful to apparatus on which it occurred. When a small transformer was connected between ground and the terminals of generators, for testing purposes, an unexpectedly high voltage appeared in an erratic manner, which punctured the generator insulation. Sometimes a high voltage and sometimes a low one was obtained, depending on the part of the cycle at which the switch was closed.

When the phenomenon was reproduced in a laboratory at that time, curves similar to those of figure 2 of the paper by Odessey and Weber were obtained by measurement and also by calculation, using the saturation curve of the transformer magnetizing current. An oscillograph was used to show that the current contained prominent harmonics, particularly when the larger of the two voltages was obtained.

A few years later, the writer observed this phenomenon in connection with a high-voltage insulator test, where again it gave trouble, as it did in some other cases noticed. See the discussion in AIEE Transactions, 1914, page 996, the article by L. Fleischmann in the *General Electric Review*, April 1924, page 260, and the article "Abnormal Behavior of Iron-Cored Reactors in Condensive Circuits" by H. B. Dwight, *Electric Journal*, 1924, volume 21, page 324.

Recently the phenomenon was described as a case of trouble in testing, by B. L. Goodlet, *Journal* of the Institution of Electrical Engineers (England), 1937, volume 80, page 490, and in a discussion on page 329 of volume 82, 1938, E. V. Clark of Australia described its use as a college laboratory experiment.

Very truly yours,
H. B. Dwight (A'11, F'26)

(Professor of Electrical Engineering, Massachusetts Institute of Technology, Cambridge)

Tensors—in Words of One Syllable

To the Editor:

Albert Einstein in his new book ("The Evolution of Physics," by Albert Einstein and L. Infeld, New York, 1938, Simon and Schuster, page 226) says, "Modern physics is simpler than the old physics and seems, therefore, more difficult and intricate." That is, while the reasoning becomes simpler the necessary groundwork becomes more extensive. So it is with the tensor, for its power lies in the simplification it affords. Like every progressive innovation in symbolic mathematics, it involves a condensation of reasoning. But the obscurity of the symbolism tends to increase in proportion to the gain in compactness. The brevity of the tensor, its best quality, is the greatest source of difficulty for the student. We are dealing here with one of those abstract physico-mathematical concepts which are usually well understood only after long acquaintanceship and patient application. A great many of us are trying vainly to cover too much ground in a single step.

Professor Skilling's straightforward article is therefore most timely and welcome. His scope is small enough to allow him to discuss in simple language just what a tensor is, without too much abstraction. But to gain a good understanding of the subject by the reading of any single article seems to be asking too much. One should read the references listed, as they are all good ones. By reading them all, one should gain a basic familiarity with the field. I would like to add Kron's articles in the *General Electric Review*.

Among textbooks, it would be hard to find any as elegant, masterful, and straightforward as Gibbs-Wilson. Wills, it is true, being more recent, is more up-to-date and takes advantage of the newer notation, but it is not as good a book for study without tutoring. Sheppard should not be missed by anyone seriously interested in tensors. Going beyond the books listed, the student will find much excellent material in some of the works on relativity.

Skilling's emphasis on the fact that the tensor is a shorthand representation of a whole group of related but distinct physical entities is important, for it is fundamental that the ensemble is treated mathematically as a single individual. The illustration of

the d-c network in terms of the vector notation is a clever adaptation of the method to the simplest possible case, familiar to all. It seems a more useful example than the one about the springs, though to a person with a good theoretical knowledge of elasticity, the latter would be better. Substitution of words in place of symbols makes the discussion of the vector idea much clearer than it would have been otherwise.

The use of sample numerical problems in these articles cannot be commended too highly. Many scientific men find it difficult to express their results in terms of homely, numerical examples. Unfortunately, few readers not trained expressly in the formal logic of mathematical demonstration are able to handle *pure* scientific articles. We need more authors who will summarize their papers by means of elementary numerical examples. Let's have more articles like the present one.

Very truly yours,
ELLIS BLADE (A'35)

(Technical Consultant, John Chatillion and Sons, New York, N. Y.)

D-C Transformers and Transmission

To the Editor:

T. C. Lennox and E. V. De Blieux in a very interesting paper "A D-C Transformer," published in the TRANSACTIONS section of the September 1938 issue of ELECTRICAL ENGINEERING on pages 554 to 558, describe a device using a mechanical commutator in conjunction with stationary transformers to transform direct current from one voltage to another.

In the discussion of this paper and C. C. Herskind's paper "New Types of D-C Transformers" which was published in the November 1937 issue (in which d-c transformers of the mercury-tube type are described, J. J. Linebaugh suggests that "perhaps the d-c transformer of the future will be a combination of the two lines of attack covered by these papers."

It might be of interest to some of the readers to know that a "combination of the two lines of attack" has been studied and successfully tried by the writer and Doctor Klaus Froehmer at the research laboratories of the AEG, Berlin, Germany, in 1932.

Although the prime object of this study was not so much the development of a d-c transformer but rather the transmission of power from one a-c system to another by means of direct current of high voltage, it is obvious that the principles involved are applicable to the d-c transformer as well as the d-c transmission circuit since the two problems differ only inasmuch as the sequence of rectification and inversion is reversed.

In our experiments we tried to overcome the difficulties which result from the unsatisfactory breakdown voltage of gas or vapor-filled vacuum tubes when applied to high-voltage transmission circuits.

As shown in the wiring diagram, figure 1, both at the rectifier and the inverter end of a d-c transmission system a rotating commutator was used whose purpose it was to connect the mercury vapor tubes to the windings of the rectifier and inverter transformer, respectively, only at such times when they were supposed to carry the current. After the current ceases to flow over an anode it is immediately disconnected by the separation of the rotating segment and the stationary brush of the commutator. The connection is re-established shortly before the current commences to be carried by the anode again. It is obvious that in this way the commutator is relieved of the duty of interrupting the current since the anode current is extinguished before the contact is broken by the process of commutation in the tube circuit. The vacuum tubes in turn are relieved from the stress of the high inverse voltage during the periods of nonconduction, since the high inverse voltage will now appear across the insulating gap between the brush and the segment of the commutator.

With a suitable design of the commutator it is thus possible to take care of voltages which considerably exceed the breakdown voltages of gas- or vapor-filled vacuum tubes. As the commutator does not function in this combination as a current interrupter it is more appropriate to describe it as a "synchronous disconnector switch."

With the experimental disconnector switch shown in the photograph, figure 2, and six mercury-vapor tubes in three-phase full-wave connection, 300 kw was rectified and a d-c voltage of 75,000 was obtained without any arcing or flashover.

The disks were made of compressed layers of paper with a resinous compound in which segments of brass were laid in. The brushes consisted of resilient German silver; they were mounted on a ring which could be angularly shifted in operation by means of a remote control arrangement. A four-kw synchronous motor was used to drive the rotating disks at a speed of 1,500 rpm.

It is to be hoped that the combination of tube circuits and mechanical commutators will be given further study since it offers interesting possibilities. Each partner to this combination namely, eliminates the inherent weakness of the other one, that is, the insufficient breakdown voltage of vacuum tubes and the arcing of rotating commutators.

Very truly yours,
HANS LAUB (M'36)

(Chief Engineer and Assistant to the President, Hanovia Chemical and Manufacturing Company, Newark, N. J.)

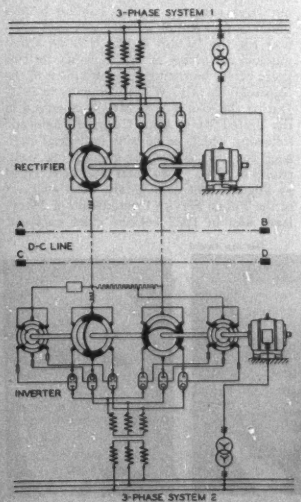

Figure 1

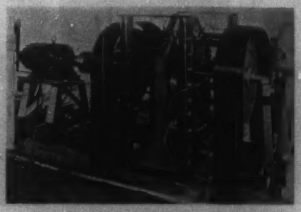
Figure 2

Some Electronic Switching Circuits

To the Editor:

Referring to the letter to the editor by H. A. Brown and P. W. Ryburn, published on page 36 of the August 1938 issue of ELECTRICAL ENGINEERING and to the last paragraph of my article "Some Electronic Switching Circuits" on page 211 in the May 1938 issue, I would like to point out that this paragraph states that the minimum R_1C_2 product rather than the minimum impulse interval would be 0.25 microsecond. There is considerable difference in meaning because the time constant, as Brown and Ryburn are aware, gives the time only for the interval during which the voltage across the condenser C_1 has dropped to about 37 per cent of its peak value. The impulsing interval, while dependent on the time constant, will be much greater since the voltage must drop approximately exponentially below the deionizing potential of the type-885 tube before the 885 will stop conducting and the cycle can be repeated.

The range of values given for the R_1C_2 product was taken directly from sweep-circuit data, where C_2 is the value of the external capacitor. The circuit capacitances, while negligible for large values of C_2, would not be negligible, of course, with small values of C_2.

In the investigation reported in this paper, the operation of the switching circuits was the primary interest. An exhaustive study of impulsing circuits was not needed since these could easily be made to have time constants appreciably lower than those of the switching circuits.

For the circuit shown by Brown and Ryburn I believe that an impulse interval of one microsecond is a noteworthy accomplishment.

Very truly yours,
C. C. SHUMARD (M'37)

(Radio Engineer, RCA Radiotron Division, RCA Manufacturing Company, Inc., Harrison, N. J.)

Personal Items

E. C. Crittenden (A'19, M'22) has been appointed chairman of the Institute's committee on research. Mr. Crittenden was born in 1880 at Oswayo, Pa., and received the degree of bachelor of arts at Cornell University in 1905. Following his graduation in 1905 he continued graduate studies at Cornell and was appointed instructor in physics, a position he held until he became assistant physicist in the National Bureau of Standards, Washington, D. C., in 1909. Subsequently he was appointed associate physicist and physicist. During 1915–17 he was chief of the illuminating-engineering section and during the periods 1917–18 and 1920–21 he was chief of the photometry and illuminating engineering section. Since 1921 Mr. Crittenden has been chief of the electrical division of the National Bureau of Standards, and in 1933 was designated also as assistant director for research and testing. Mr. Crittenden has represented the United States at recent meetings of the International Committee on Weights and Measures; was president of the United States National Committee of the International Commission on Illumination from 1929 until 1935, and was a delegate to the sessions of that commission held in 1924, 1928, and 1931. He was president of the Illuminating Engineering Society during 1935, and of the Optical Society of America during 1932–33.

J. D. Wood (A'19, M'27) has been elected president of the Roller-Smith Company, New York, N. Y. Mr. Wood was born November 30, 1894, at Wichita, Kansas, and received the degree of bachelor of science from both Guilford College (1915) and Haverford College (1916); in 1917 he received the degree of master of arts from Haverford. In 1918 he was employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and after completing the graduate student course of that company he was transferred to the supply engineering department. Later he became engaged in the development of protective devices and remained with the Westinghouse Company until 1923. In that year he resigned to become engaged in the design of oil circuit breakers for the General Electric Company, Schenectady, N. Y. Later in the same year he became division engineer for the Condit Electrical Manufacturing Corporation, Boston, Mass., and remained there until 1929, when he joined the engineering staff of the Roller-Smith Company at Bethlehem, Pa. At the time of his election to the presidency of the company he was chief engineer.

E. C. M. Stahl (M'27) has been appointed chairman of the Institute's committee on power generation for the year 1938–39. Mr. Stahl was born at St. Paul, Minn., in 1891 and was graduated from Cornell University with the degree of mechanical engineer in 1913. Following his graduation he became a special apprentice for the New York Central Railroad, and in 1914 became a draftsman. During the World War Mr. Stahl held a commission as captain in the Coast Artillery Corps of the United States Army, returning to the New York Central Railroad in 1919 as an inspector in the electrical department. Following a brief association with the Pittsburgh Transformer Company he was appointed electrical field engineer for the Brooklyn Edison Company, Inc., in 1922, and in 1926 was appointed assistant superintendent of the Hudson Avenue station of that company. In 1928 Mr. Stahl was appointed engineer of tests and two years later became assistant operating superintendent. In 1934 he was made operating superintendent of the Brooklyn Edison Company, and in 1937 was transferred to the Consolidated Edison Company of New York, Inc., as assistant manager of production.

M. J. McHenry (A'11, M'20, vice-president) has been appointed director of sales promotion of the Hydro Electric Power Commission of Ontario. Mr. McHenry was born at Catasauqua, Pa., in 1888, and received the degree of bachelor of science in electrical engineering at McGill University in 1910. Following his graduation he was employed by Smith, Kerry, and Chase, a Toronto firm of consulting engineers, until 1912. In that year he was employed by the Canadian General Electric Company as sales engineer in Toronto, and in 1916 he became assistant manager of apparatus sales in the Toronto district. In 1918 Mr. McHenry became manager and secretary-treasurer of the Walkerville Hydro-Electric System and remained as chief executive of that system until 1924. In that year he became sales manager of the Ferranti Electric Company, Ltd., which position he relinquished in 1926 to become manager of the United States sales department of the Canadian General Electric Company. In 1930 he was appointed district manager for Ontario, a position he held until his recent appointment to the Hydro-Electric Power Commission.

C. M. Laffoon (A'24) has been appointed chairman of the Institute's committee on electrical machinery for the year 1938–39. At present manager of the a-c generator engineering department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., Mr. Laffoon was born at Coldwater, Kans., in 1888, and was graduated in electrical engineering from the University of Missouri in 1914. He then received an appointment as research assistant at the University of Missouri, enrolled as a graduate student, and received the degree of master of arts in 1915. Following a year of construction engineering for a firm of consulting engineers in Kansas City, Mo., he became affiliated with the Westinghouse Company in 1916. He has presented several papers on electrical machinery before the Institute, and has been an extension lecturer in the graduate school of the University of Pittsburgh for the last several years.

H. C. Wolf (A'16, M'23) has been elected president of the Atlanta Gas Light Company, Atlanta, Ga. Mr. Wolf is a native (1891) of Edwardsville, Ill., and a graduate of the University of Illinois with the degrees of bachelor of science, master of science, and electrical engineer. After holding a preliminary position he became assistant engineer for the Illinois Public Utilities Commission, remaining in that capacity for two years before becoming superintendent of the Edwardsville (Ill.) Water Company in 1916. During the World War Mr. Wolf served in the United States Army Corps of Engineers, following which he became industrial engineer for two consulting-engineering companies in 1929. Two years later he received an appointment as assistant chief engineer of the Public Service Commission of Maryland, and in 1922 became chief engineer.

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Gas Age Record

E. C. M. STAHL J. D. WOOD C. M. LAFFOON H. C. WOLF E. C. CRITTENDEN

R. M. HENDERSON

Bachrach

H. W. CODDING

M. F. SKINKER

H. R. CRUMLEY

Electrical World

D. L. BEMENT

In 1929 Mr. Wolf resigned to become assistant to the vice-president of the Central Public Service Corporation. In 1933 he became vice-president of the Consolidated Electric and Gas Company, and in 1934 moved to Muncie, Ind., to assume the duties of president of the Central Indiana Gas Company and associated companies in Indiana under common ownership and under the management of the Stone and Webster Service Corporation. The Atlanta Gas Light Company also is a Stone and Webster property.

R. M. Henderson (A'07, M'13) has been elected vice-president of United Engineers and Constructors, Inc., with offices at Chicago, Ill. Mr. Henderson was born at Willoughby, Ohio, February 2, 1879, and received the degrees of bachelor of science in electrical engineering (1902) and electrical engineer (1906) at Armour Institute of Technology. Following a period as electrical engineer for the Mexican Central Railway during 1902–04, he returned to the United States to become an engineer for the Arnold Company, Chicago. In 1907 he became affiliated with Stone and Webster, Inc., Boston, Mass., holding successively the positions of construction engineer, assistant construction manager, and district manager in the Chicago offices. From 1918 until 1928 Mr. Henderson was a vice-president of Dwight P. Robinson and Company, Inc., New York, N. Y. When that company was merged with three other firms to form the United Engineers and Constructors, Inc., in 1928, Mr. Henderson was appointed president of the Canadian subsidiary corporation of the new organization. Since 1932 he has been midwest manager of the company.

Eugene Holcomb (A'03) has retired from active service with the Consumers Power Company, Jackson, Mich., after 15 years as a member of the general office executive staff. A native (1868) of Cedar Springs, Mich., Mr. Holcomb first became identified with the electrical industry as an engineer in the California district of the Thomson-Houston Electric Company in 1887. Three years later he became assistant district engineer for the Edison General Electric Company, Portland, Ore., and in 1892 was made assistant manager of the Portland offices of the General Electric Company. Later he and some associates leased and operated the Capital Electric Company properties in Springfield, Ill. Subsequently he was associated with the export department of the Westinghouse Electric and Manufacturing Company in New York, N. Y., and in Buenos Aires, Argentina; with the foreign sales department of the Allis-Chalmers Manufacturing Company at Milwaukee, Wis., and with H. M. Byllesby and Company at St. Paul, Minn. Mr. Holcomb returned to Michigan in 1913 to become president of the Continental Utilities Company at Lansing, continuing in that position for several years. He served also as general manager of the Central Michigan Light and Power Company, with headquarters at Alma. That property was acquired by the Consumers Power Company in 1924, and Mr. Holcomb was assigned to the executive staff at Jackson.

H. W. Codding (A'19, M'25) has been appointed chairman of the Institute's committee on automatic stations. Mr. Codding was born at Providence, R. I., in 1889 and was graduated from Massachusetts Institute of Technology with the degree of bachelor of science in electrical engineering in 1912. Following his graduation he received an appointment as cadet engineer for the Public Service Railway Company, Newark, N. J., and three years later was assigned to the distribution department of that company. In 1917 Mr. Codding became assistant to the chief electrical engineer of The New York Edison Company, New York, N. Y., but returned two years later to the Public Service Railway Company as engineer in the distribution department. In 1920 he became distribution engineer in charge of the engineering work of the distribution department and was appointed assistant engineer in the electrical engineering department of the Public Service Production Company in 1924. Later he received a similar appointment in the Public Service Electric and Gas Company, Newark. For a time Mr. Codding was associated with United Engineers and Constructors, Inc., in Newark.

M. F. Skinker (A'22, F'34) has been appointed chairman of the Institute's committee on electrochemistry and electrometallurgy. Doctor Skinker was born at Denver, Colo., in 1898 and received the degrees of bachelor of science in electrical engineering (1919) and master of science (1921) at the University of Colorado. Following his graduation in the latter year he received a Rhodes scholarship at Oxford University, where he pursued research on the conduction of electricity in gases, receiving the degree of doctor of philosophy there in 1924. He then returned to the United States and became assistant research engineer in the electrical engineering department of the Brooklyn Edison Company, Inc., Brooklyn, N. Y. In 1926 Doctor Skinker was appointed assistant director of research of that company, and in 1937 he became director of research.

H. R. Crumley (A'26, M'37) has been appointed general superintendent of the Virginia Public Service Company, with offices at Charlottesville. Mr. Crumley was born in Atlanta, Ga., in 1900 and was graduated from the Georgia School of Technology with the degree of bachelor of science in electrical engineering in 1920. Following his graduation he was employed on the test course of the General Electric Company at Schenectady, N. Y., but remained there only one year before becoming affiliated with the Georgia Railway and Power Company. In 1926 Mr. Crumley became relay engineer for the New Jersey Power and Light Company; one year later he was appointed assistant superintendent of operation, and in 1932 became chief system operator. He joined the E. M. Gilbert Engineering Corporation, Reading, Pa., as electrical engineer in 1937, and later became consulting engineer for The Utility Management Corporation, Reading.

D. L. Bement (A'25) has been elected vice-president of the Northern Indiana Public Service Company, Hammond. Mr. Bement is a native (1900) of Goshen, Ind., and an electrical engineering graduate of Purdue University of the class of 1922. Following his graduation he became a cadet engineer for the Northern Indiana Public Service Company and has remained in the employ of that organization continuously. In 1924 Mr. Bement was appointed assistant superintendent of electric distribution and later became general electric superintendent of the system.

W. T. Teague (A'19) retired recently as director and vice-president of the Western Electric Company, New York, N. Y., after a service of 37 years with the Bell telephone system. Born at Napa, Calif., Mr. Teague began his career in communications in the

San Francisco office of the telephone company. Eight years later he was made district superintendent of the Sacramento offices of the Bell Telephone Company; later, after having served several years in Portland, Ore., as division superintendent of plant, he returned to San Francisco to be placed in charge of the engineering and construction of an important line. In 1920 he became plant superintendent at Cleveland, Ohio, and three years later was transferred to New York to assist in the organization and administration of the new installation department of the Western Electric Company. Later he became manager of that department, and in 1927 was elected vice-president and a director.

R. L. Webb (A'29, M'35) has been appointed chairman of the Institute's committee on membership. Born at Phelsenthal, Ark., in 1904, Mr. Webb received the degree of bachelor of science in electrical engineering at Rice Institute in 1926, before being employed on the test course of the General Electric Company at Schenectady, N. Y., and Pittsfield, Mass. In 1927 he was transferred to the relay design department of the General Electric Company at Schenectady and later at Philadelphia, Pa., where he remained until he was appointed assistant engineer for the Brooklyn Edison Company, Inc., Brooklyn, N. Y., in 1929. Mr. Webb was transferred to the electrical engineering department of the Consolidated Edison Company of New York, Inc., in 1937. He has been assistant chairman of the AIEE committee on membership since 1936, and has participated in committee work of the Association of Edison Illuminating Companies and the Edison Electric Institute.

H. H. Race (A'24, M'31) has been appointed chairman of the Institute's committee on Sections for the year 1938–39. A native (1899) of Buffalo, N. Y., he was graduated from Cornell University with the degrees of electrical engineer (1922) and doctor of philosophy (1927). Following his graduation in 1922, Doctor Race became a design engineer in the transmission and distribution department of the Philadelphia (Pa.) Electric Company, but in 1923 returned to Cornell as an instructor in advanced electrical theory. He continued in that position until he was appointed assistant professor in 1927. Since 1929 Doctor Race has been a research engineer in the research laboratories of the General Electric Company, Schenectady, N. Y. In 1928 Doctor Race was awarded the AIEE National and North Eastern District prizes for initial paper. He is a member of the Institute's committees on planning and coordination, basic sciences, and research.

E. L. Splitstone (A'19, M'23) has been appointed chief engineer of the Emerson Electric Manufacturing Company, St. Louis, Mo. Mr. Splitstone was born at Kinsman, Ohio, in 1888 and was graduated from The Ohio State University in 1911. Following a brief affiliation with the Pennsylvania Railroad he worked for the Hydraulic Power Company, Niagara Falls, N. Y. In 1912 he became affiliated with the Emerson Electric Manufacturing Company as an assistant testing engineer. In 1913 Mr. Splitstone was made performance engineer; two years later he became commercial engineer; and he was chief production engineer from 1920 until his recent appointment as chief engineer. Mr. Splitstone has been active in committee work of the National Electrical Manufacturers Association.

W. S. H. Hamilton (A'19, M'26) has been appointed chairman of the AIEE committee on transportation for the year 1938–39. Mr. Hamilton was born at New Haven, Conn., in 1890, and attended Yale University before entering the testing department of the General Electric Company, Schenectady, N. Y., in 1911. Two years later he was transferred to the railway equipment engineering department, where he remained until 1918. During the World War Mr. Hamilton served as an engineer officer on a United States naval transport, following which he returned to the employ of the General Electric Company, remaining until 1931. In that year he was appointed assistant electrical engineer for the New York Central Railroad, and since 1934 he has been equipment electrical engineer.

H. P. Liversidge (A'12, M'17, past director) has been elected president of the Philadelphia Electric Company, Philadelphia, Pa. Mr. Liversidge was born at Norristown, Pa., September 29, 1878, and received his technical education at Drexel Institute, being granted the degree of bachelor of science in electrical engineering in 1898. Mr. Liversidge has been associated with the Philadelphia Electric Company continuously since 1898, having served successively as assistant superintendent of operation, assistant superintendent of station design and construction, operating engineer, assistant chief engineer, chief engineer, and vice-president and general manager. Mr. Liversidge served as a director of the Institute from 1927 until 1931.

G. L. Crosby (A'15, M'26) has been elected vice-president of the Roller-Smith Company, New York, N. Y.; he will retain the duties of general sales manager. Mr. Crosby was born at Brookhaven, Miss., in 1883 and attended Millsaps College (Miss.) and George Washington University before becoming sales engineer and manager of the Cleveland (Ohio) offices of the Cutter Company in 1902. Two years later he entered the employ of the Stanley-G. I. Electric Manufacturing Company as a sales engineer, but when that company was dissolved in 1905 he established his own sales-engineering offices at Cleveland under the firm name of Crosby, Craft, and Company. In 1910 Mr. Crosby became affiliated with the Roller-Smith Company as sales engineer and manager of the Pittsburgh (Pa.) offices. In 1912 he was transferred to the New York offices of the company and became successively general sales manager, assistant to the president, and vice-president in charge of sales.

G. L. CROSBY

C. B. Aiken (M'35) has established consulting engineering offices in the firm of McCutchen and Aiken at New York, N. Y. A native (1902) of New Orleans, La., Doctor Aiken was graduated from Tulane Univer-

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R. L. WEBB

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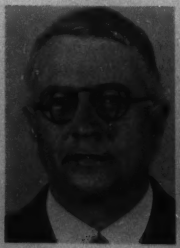
H. P. LIVERSIDGE

E. L. SPLITSTONE



W. S. H. HAMILTON

Bachrach

H. H. RACE

sity with the degree of bachelor of science in 1923. He then enrolled in the graduate school of Harvard University and received there the degrees of master of science (1924), master of arts (1925), and doctor of philosophy (1933). From 1926 until 1928 he was engaged in geophysical exploration with the firm of Mason, Schlichter, and Hay, Madison, Wis., and during the period 1928–35 was a member of the technical staff of Bell Telephone Laboratories, Inc., New York. Doctor Aiken was associate professor of electrical engineering in charge of communication at Purdue University, Lafayette, Ind., from 1935 until 1938.

J. D. Wright (A'36) has been appointed chairman of the AIEE committee on industrial power applications for the year 1938–39. Mr. Wright, who is assistant manager of the industrial department, General Electric Company, Schenectady, N. Y., is a native (1887) of Baraboo, Wis., and a

J. D. WRIGHT

graduate of the University of Wisconsin in the class of 1909. Following his graduation he became a student engineer in the testing department of the General Electric Company, and has remained in the employ of that organization continuously, having been successively an engineer in the industrial control engineering department, engineer in the steel mill section, engineer in charge of the steel mill section, assistant engineer in the industrial department, and manager of that department.

W. F. Hess (A'32) has been elected a vice-president of the American Welding Society. After having received the degrees of electrical engineer (1925) and doctor of engineering (1928) at Rensselaer Polytechnic Institute, Troy, N. Y., Doctor Hess served from 1928 until 1930 as an instructor in electrical engineering. In the latter year he was appointed assistant professor of electrical engineering and physics. In 1937 he was made assistant professor of metallurgy and was placed in charge of the welding laboratory, and one year later he received an appointment as associate professor of metallurgical engineering.

John Harisberger (A'02, M'10) has retired as general superintendent of the division of power supply of the Puget Sound Power and Light Company, Seattle, Wash., after a service of 40 years with that utility company and its predecessors. Mr. Harisberger was born December 2, 1871 at Berne, Switzerland. He first became identified with the electrical industry when he was employed by the Northwest Thomson-Houston Electric Company and the Northwest General Electric Company, Portland, Ore., as a shop apprentice in 1892. As a young man he helped on the construction of the Snoqualmie Falls power plant, and upon its completion he became its first superintendent. Mr. Harisberger was a lecturer on generation and transmission of electric power at the University of Washington from 1905 until 1911, and was a member of the advisory board for the department of electrical engineering from 1916 until 1919.

K. L. Hansen (A'17, F'34) has been elected a vice-president of the American Welding Society. A native of Norway and a graduate of the University of Illinois, Mr. Hansen has held various positions with the Western Electric Company, Commonwealth Edison Company, Westinghouse Electric and Manufacturing Company, and the Louis Allis Company. Since 1932 Mr. Hansen has been consulting engineer for the Harnischfeger Corporation, Milwaukee, Wis. He is a member of the Institute's committee on electric welding and is a past chairman of the AIEE Milwaukee Section.

H. M. Sharp (M'34) vice-president in charge of plant operations for the Buffalo, Niagara, and Eastern Power Corporation, incorrectly was stated to have been elected general secretary of the Illuminating Engineering Society, on page 435 of the October issue. H. M. Sharp (nonmember) manager of the lighting bureau of the same company, has been elected to this office.

C. A. Adams (A'94, F'13, past president) has been elected a director-at-large of the American Welding Society. For many years Doctor Adams was professor of electrical engineering at Harvard University, and at present is professor emeritus at that institution. He was the founder and first president of the American Welding Society, and is an honorary member. He is a member of the AIEE committee on electric welding.

G. C. Sears (A'19, M'20) has become general superintendent of the division of power supply of the Puget Sound Power and Light Company, Seattle, Wash. Mr. Sears formerly was superintendent of power plants and transmission lines. A native (1884) of Salem, Ore., he has spent his entire technical career in the employ of the Puget Sound Power and Light Company during a period covering more than 36 years.

E. W. Conroy (M'32) who has been assistant to the general superintendent of light and power of the Puget Sound Power and Light Company, Seattle, Wash., has become superintendent of transmission. A native (1894) of Helena, Mont., and an electrical engineering graduate of the University of Washington, Mr. Conroy has been employed continuously by the company since 1922.

J. A. Cranston (A'08) recently was awarded an honorary life membership in the San Francisco (Calif.) Electrical Development League. He is a retired commercial vice-president of the General Electric Company. A biographical sketch of Mr. Cranston appeared on page 324 of the July 1938 issue of ELECTRICAL ENGINEERING, at the time of his retirement from active service.

F. T. Hague (A'14) incorrectly was associated with the General Electric Company in an item on page 436 of the October 1938 issue of ELECTRICAL ENGINEERING. Mr. Hague has been made manager of engineering of the steam division of the Westinghouse Electric and Manufacturing Company at the South Philadelphia (Pa.) works.

J. F. Calvert (A'27, M'35) has become professor of electrical engineering at Northwestern University, Evanston, Ill. Previously professor of electrical engineering at Iowa State College, Ames, he was once associated with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for thirteen years, and was lecturer at the University of Pittsburgh during his affiliation with the Westinghouse Company.

W. J. Schuhmann (A'24) recently was elected treasurer of the Roller-Smith Company, New York, N. Y. Mr. Schuhmann is a native (1901) of New York, N. Y. He attended Pratt Institute and the Polytechnic Institute of Brooklyn (N. Y.), and has been associated with the Roller-Smith Company since 1916, first in the accounting department and later in the sales department.

R. M. Baker (A'35) now is employed in the research laboratories of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Until recently Mr. Baker was an instructor in electrical engineering at the Kansas State College of Agriculture and Applied Science, Manhattan.

P. G. Agnew (A'12, M'19) has been elected an honorary member of the American Home Economics Association in recognition of his part in organizing work on standards for consumer goods. Doctor Agnew is secretary of the American Standards Association, New York, N. Y.

K. V. Abakumoff (A'28) has been appointed assistant electrical engineer in the breau of engineering, United States Department of Agriculture, Washington, D. C. Formerly Mr. Abakumoff was assistant electrical engineer for the Metropolitan Water District of Southern California, Los Angeles.

E. K. Rohr (A'37) now is employed in the electrical engineering department of North Dakota State College, Fargo. Previously Mr. Rohr was a mechanician in the electrical engineering department of Iowa State College, Ames.

E. L. White (A'26) now is employed on the Bonneville Project, Portland, Ore. Mr. White has been a communication engineer for the Puget Sound Power and Light Company, Seattle, Wash.

W. W. Glenny (A'38) has enrolled in the graduate school of Purdue University, Lafayette, Ind., and has been appointed to an assistantship in the department of engineering extension of the university. Mr. Glenny has been an electrical engineer for the Reliance Electric and Engineering Company, Cleveland, Ohio.

S. L. Guthorn (M'20) has been appointed superintendent of the New York group, National Park Service, United States Department of the Interior, New York, N. Y. Formerly Mr. Guthorn was superintendent of the National Park Service at Washington, D. C.

W. H. Mansfield (A'27) has been appointed Florida plant superintendent of the Southern Bell Telephone and Telegraph Company, Inc., with offices at Jacksonville. Formerly Mr. Mansfield was Mississippi plant superintendent of the company at Jackson.

H. H. Davenport (A'38) has become a member of the firm of the Audiphone Company of South Texas, San Antonio, Texas. Formerly Mr. Davenport was employed in the plant department of the Southwestern Bell Telephone Company, Corpus Christi, Texas.

R. C. Green (A'38) has become an instructor in electrical engineering at the Texas Agricultural and Mechanical College, College Station. Mr. Green has been a student engineer for the Dallas (Texas) Power and Light Company.

F. J. Zak (A'32) has become superintendent of distribution for the Fredericksburg district of the Virginia Electric and Power Company. Mr. Zak has been system engineer in the Richmond offices of the company.

M. B. Reed (A'36) has become a member of the electrical engineering department of Armour Institute of Technology, Chicago, Ill. Formerly he was assistant professor of electrical engineering at the University of Texas, Austin.

H. H. Bates (A'36) has been transferred to Detroit, Mich., as district plant engineer in the long lines department of the American Telephone and Telegraph Company. Mr. Bates has been employed in the Cleveland (Ohio) offices of the company.

R. C. Martin (A'34) has become assistant to the district manager of the Pacific Power and Light Company, Yakima, Wash. Mr. Martin has been employed in the technical control department of the Willamette Paper Company, Camas, Wash.

M. G. Marshall (A'37) now is affiliated with the James R. Kearney Corporation, St. Louis, Missouri. Formerly Mr. Marshall was an electrical engineer for the Commonwealth and Southern Corporation, Jackson, Mich.

R. M. Wainwright (A'37) has been appointed corrosion engineer for the Montana-Dakota Utilities Company, with field offices at Glendive, Mont. Mr. Wainwright formerly was assistant corrosion engineer for the Montana Power Company, Butte.

E. U. Thomas (A'36) recently became an engineer in the automotive division of the Gulf Research and Development Company, Pittsburgh, Pa. Previously Mr. Thomas was an engineer for the Union Switch and Signal Company, Swissvale, Pa.

F. S. Bacon, Jr. (A'37) recently was transferred from the general sales department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., to the central station division of the company in Boston, Mass.

E. F. Schuster (A'37) has been employed as assistant electrical engineer with the Underwriter's Laboratories, Inc., New York, N. Y. Previously Mr. Schuster was a tester for the American Transformer Company, Newark, N. J.

R. A. Krasovec (A'31) has just completed an electrical project for the American Smelting and Refining Company at Bonanza, Nicaragua, and now is an electrical engineer for the United States Works Progress Administration at New York, N. Y.

E. J. Schiller, Jr. (A'38) has received an appointment as instructor in the department of machine design at Cornell University, Ithaca, N. Y. Mr. Schiller is studying for his master's degree in electrical engineering at Cornell.

W. S. Gordon, Jr. (A'27, M'35) has been appointed electrical engineer in the office of the constructing quartermaster, McChord Field, Fort Lewis, Wash. Formerly Mr. Gordon was supervising engineer for Vare Brothers, Philadelphia, Pa.

J. G. Barry (A'38) has become affiliated with the Bartol Research Foundation, Swarthmore, Pa. Formerly Mr. Barry was enrolled as a graduate student in the Moore School of Electrical Engineering at the University of Pennsylvania.

H. R. Stoddard (A'32) has been transferred to the Chicago (Ill.) district of the Simplex Wire and Cable Company. Mr. Stoddard previously was employed in the electrical engineering department of the company at Cambridge, Mass.

Norman Arnold (A'29, M'37) has become assistant professor of engineering drawing at Purdue University, Lafayette, Ind. Formerly he was assistant professor of general engineering drawing at the University of Illinois, Urbana.

G. W. Miller (A'35) has been transferred to the Zanesville, Ohio offices of the Line Material Company. Mr. Miller is an inspector for the company and previously was employed in the South Milwaukee, Wis., offices of the company.

Ray Blain (A'24, M'31) has been transferred to the office of the chief signal officer, United States Army Signal Corps, Washington, D. C. Previously Mr. Blain was a telephone plant engineer in the signal service at large, Omaha, Neb.

R. A. Galbraith (A'38) has joined the faculty of the electrical engineering department of the University of Missouri, Columbia. Formerly Mr. Galbraith was an engineer in the research department of The Detroit Edison Company, Detroit, Mich.

L. G. Brewer (A'37) has been appointed assistant superintendent of distribution for the Montana Power Company, with offices at Great Falls. Mr. Brewer formerly was distribution engineer in the Havre offices of the company.

W. McC. Runyon (A'20) has become a sales engineer in the Pittsburgh (Pa.) offices of the National Electric Products Corporation. Mr. Runyon has been a development sales engineer for that company, with offices at Ambridge, Pa.

J. I. Holbeck (A'24, M'36) has been appointed to the engineering staff of the Bonneville project at Portland, Ore. For the last 14 years Mr. Holbeck has been associated with the Minnesota Power and Light Company as relay engineer at Duluth.

I. J. Sattinger (A'36) now is employed as an electrical draftsman for the Loup River Public Power District, Columbus, Nebr. Formerly he held a similar position with the Commonwealth and Southern Corporation, Jackson, Mich.

Frank Worel (A'29) has been transferred to the Ypsilanti offices of the Michigan Bell Telephone Company as repair foreman. Formerly he was exchange repairman at Grand Rapids.

A. H. Pedersen (A'32) has been transferred to Toledo, Ohio, as assistant foreman for the Gulf Oil Corporation. Mr. Pedersen formerly held a similar position in the Philadelphia (Pa.) offices of that company.

Harold Gerard (A'36) has become an electrical designer for the firm of Holway and Neuffer, Tulsa, Okla. Mr. Gerard has been an electrical engineer for the Pierce Electric Company, Chicago, Ill.

L. R. Waugh (A'09, F'33) recently was appointed assistant project engineer for the United States Public Works Administration on the construction of the Grand River Dam and hydroelectric power plant in Oklahoma.

W. N. Clark (A'05, M'36) has been elected president of the Rocky Mountain Electrical League. Mr. Clark is president and manager of the Southern Colorado Power Company, Pueblo, Colo.

W. H. Bliss (A'30) has become an instructor of electrical engineering at the University of Maine, Orono. Mr. Bliss has been employed as a research engineer for RCA Communications, Inc., New York, N. Y.

V. A. Hanson (A'34) has resigned as vice-president and chief engineer of the Power Transmission Council, Boston, Mass., to become associated with the Whitney Chain and Manufacturing Company, Hartford, Conn.

O. A. Becklund (A'38) has been appointed instructor in the department of electrical engineering at the Case School of Applied Science, Cleveland, Ohio.

O. W. Muckenhirn (A'38) has become an instructor in the department of electrical engineering at the University of Minnesota, Minneapolis.

Peter Fries, Jr. (A'34) counselor at law, New York, N. Y., has been admitted to practice in the United States Patent Office as a patent attorney.

Harry Dunseath, Jr. (A'34) has become a draftsman for the consulting-engineering firm of Hunter and Hudson, San Francisco, Calif.

Obituary

Edwin Stafford Reid (A'96, M'12) died July 20, 1938. Mr. Reid was born May 21, 1865, at Brooklyn, N. Y. In 1884 he was employed by the New York Quotation Company, New York, N. Y., as inspector of instruments and after one year was placed in charge of the electrical department. In 1887 he became associated with a consulting engineer carrying on experiments and designing motors and traction operators for the elevated railway systems in New York. Mr. Reid became electrical engineer and superintendent of the Eastern Department of the Standard Underground Cable Company in 1889, and is said to have installed the first underground electric lighting system in the United States during his stay with that company, which lasted until 1896. In the latter year he became electrical and construction engineer for the National Conduit and Cable Company, becoming chief engineer of the British branch of the company in 1899. He later became European manager and electrical engineer for the company in both England and the United States. Mr. Reid served briefly as an engineer for the American Brass Company before retiring from active service in 1926 to devote a part of his time to consulting work in electrical engineering.

Walter J. Ducey (A'22, M'30) died September 29, 1938. Assistant electrical engineer on the staff of the Commonwealth and Southern Corporation, Jackson, Mich., Mr. Ducey was born June 23, 1894, at Grand Rapids, Mich., and was graduated from the University of Notre Dame with the degree of electrical engineer in 1917. He joined the engineering department of the Consumers Power Company in 1919, and six years later was made assistant electrical engineer for the Commonwealth Power Corporation of Michigan. He continued in that position when the organization was managed successively by Stevens and Wood, Inc., and by Allied Engineers, Inc. When the latter company was dissolved in 1931, Mr. Ducey was appointed electrical engineer with the Consumers Power Company and was placed in charge of the engineering section. In 1936 the engineering department of the Consumers Power Company was merged with the Jackson engineering staff of the Commonwealth and Southern Corporation engineering clearing agent, and Mr. Ducey was appointed assistant electrical engineer. He was active in committee work of the former National Electric Light Association and of the Edison Electric Institute.

Frederick Webster Deck (M'30) senior engineer of the mechanical engineering division of the Philadelphia Electric Company, Philadelphia, Pa., died September 26, 1938. Mr. Deck was born March 28, 1896 at Washington, D. C., and received the degree of bachelor of arts at George Washington University in 1924. He then entered the University of Colorado and received the degrees of bachelor of science in civil engineering (1925) and civil engineer (1929). Following two preliminary positions, he served in the United States Army from 1917 until 1923, during which time he ultimately held a commission as captain in the Corps of Engineers. Mr. Deck entered the employ of the Philadelphia Electric Company in 1925 as a field engineer on steel tower work and later advanced to a position in full charge of all civil engineering work involving steel tower transmission line design.

James Townes Robertson (A'06, M'13) founder of the firm of J. T. Robertson and Associates, Birmingham, Ala., died September 6, 1938. Mr. Robertson was born at Abbeville, S. C., May 26, 1879, and was graduated from Clemson College with a degree in electrical and mechanical engineering in 1903. He was electrical inspector for the Southeastern Underwriters' Association, Atlanta, Ga., from the time of his graduation until 1911, when he became electrical engineer and inspector for the Mississippi Inspection and Advisory Rating Company at Vicksburg. Later Mr. Robertson was made secretary and electrical engineer, a position he held until 1925, when he became superintendent of the Abbeville Water and Electric Plant. In 1929 he became associated with the firm of A. H. Turner, Atlanta, as special agent and engineer; eight years later he established his own firm in Birmingham.

Charles Caesar Hawkins (A'03) retired electrical engineer of Kew, Surrey, England, died in August 1938. Mr. Hawkins was born March 15, 1864 at Lamberhurst, England, and was graduated from Magdalen College, Oxford, with the degree of master of arts. In 1889 he became associated with the firm of Johnson and Phillips, London, but one year later transferred his affiliation to the firm of H. Allen, Son, and Company, Ltd., Bedford. Mr. Hawkins remained with that firm until he established his own consulting electrical-engineering business in 1908 at Bedford. Later he continued his consulting practice in London until 1922, when he became secretary of the department of technology of the City and Guilds of London Institute. Later he became superintendent of that institute before retiring from active service to devote a part of his time to private consulting practice.

Eugene Maxwell (A'96) expansion department, Western Public Service Company, Scottsbluff, Nebr., died July 28, 1938. From 1888 until 1894 Mr. Maxwell was engaged in building and operating electric light plants and distribution systems in the Northwestern part of the United States and Western Canada, and from 1894 until 1911 he held various positions for street railway systems and in the construction and operation of transmission lines. In 1911 Mr. Maxwell was employed by the Mississippi River Power Company in the land and tax department and remained with that company until 1926, when he joined the expansion department of the Western Public Service Company.

Claude Francis Benham (A'16, M'26) engineer in the operation and maintenance department of the Pacific Gas and Electric Company, San Francisco, Calif., died September 12, 1938. Mr. Benham was born November 15, 1889, at Bozeman, Mont., and was graduated from the University of Minnesota with a degree in electrical engineering. Following his graduation he became a substation operator for the Great Western Power Company, remaining with that company until 1930 and eventually becoming assistant to the general superintendent. He transferred his affiliation to the Pacific Gas and Electric Company as an assistant engineer in 1931.

Glendon C. Brown (M'37) electrical engineer in the research and engineering department of Cutler-Hammer, Inc., Milwaukee, Wis., died August 10, 1938. Mr. Brown was born at Fargo, N. D., January 2, 1907, and was graduated from the University of Minnesota with the degree of bachelor of science in electrical engineering in the class of 1928. He joined the research and engineering staff of Cutler-Hammer immediately following his graduation, and served that company continuously.

Membership

Recommended for Transfer

The board of examiners, at its meeting on October 20, 1938, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Charlton, O. E., electrical engineer, Commonwealth and Southern Corporation, Birmingham, Ala.
Gray, T. S., assistant professor of engineering electronics, Massachusetts Institute of Technology, Cambridge.
Henderson, F. M., transmission engineer, Indiana and Michigan Electric Company, South Bend, Ind.

Laning, W. A., assistant professor of electrical engineering, University of Maryland, College Park.
Larner, R. A., protection engineer, Texas Electric Service Company, Eastland.
Meyers, G. J., assistant Thomson Laboratory, General Electric Company, West Lynn, Mass.
Senn, A. H., general foreman, New York and Queens Electric Light and Power Company, Flushing, N. Y.

7 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before November 30, 1938, or January 31, 1939, if the applicant resides outside of the United States or Canada.

United States and Canada

Ayvazian, A. (Member), 507 Tulsa Building, Tulsa, Okla.
Baer, J. M., Department of Water and Power, Los Angeles, Calif.
Benford, C. C., Benford Electric Motor Service, Santa Ana, Calif.
Blaisdell, K. L., Connecticut Light and Power Company, Meriden.
Bollinger, R. M., Bureau of Power and Light, Los Angeles, Calif.
Booth, A. E., 121 South Catalina Street, Los Angeles, Calif.
Breyer, J., Jr., 2134 Acklen Avenue, Nashville, Tenn.
Brockhoff, F. W., Union Electric Company of Missouri, St. Louis, Mo.
Burnside, L. L., Bureau of Power and Light, Los Angeles, Calif.
Byers, H. O., Kansas Gas and Electric Company, Wichita, Kans.
Carpenter, R. M., Southwestern Bell Telephone Company, Dallas, Texas.
Cleeland, J. L., Hickok Electrical Instrument Company, Cleveland, Ohio.
Cleveland, L. F., Northeastern University, Boston, Mass.
Collins, A. B., Langston Project, United States Housing Authority, Washington, D. C.
Connors, R. G., Lynn Gas and Electric Company, Lynn, Mass.
Elliott, R. D., Dallas Power and Light Company, Dallas, Texas.
Gammell, J., Allis-Chalmers Manufacturing Company, Philadelphia, Pa.
Garvin, W. M., Portland General Electric Company, Newberg, Oregon.
Geiger, H. J., Jr., Locke Insulator Corporation, New Orleans, La.
Gill, W. P., Tennessee Valley Authority, Knoxville, Tenn.
Gindra, H. J., Union Electric Company of Missouri, St. Louis, Mo.
Girtman, W. F., Florida Telephone Corporation, Leesburg.
Greve, L. F. (Member), Commonwealth Edison Company, Chicago, Ill.
Hallman, A. B., Eastern Air Lines, Inc., Newark, N. J.
Hays, G. T., Dallas Power and Light Company, Dallas, Texas.
Henkle, C. V. (Member), John A. Roeblings Sons Company of California, Los Angeles.
Hood, J. E., Department of Water and Power, Los Angeles, Calif.
Hoover, J. I., Hickok Electrical Instrument Company, Cleveland, Ohio.
Hoye, P. B., Electrical Engineers Equipment Company, Melrose Park, Ill.
Humak, W. P., Morganite Brush Company, Long Island City, N. Y.
Hughes, O. L., Mississippi Power and Light Company, Jackson.
Johnson, E. G., 1440 Broadway, Oakland, Calif.
Jory, J. G., The Chesapeake and Potomac Telephone Company, Washington, D. C.
Kauffman, R., Los Angeles Bureau of Power and Light, Los Angeles, Calif.
King, H. W., The Chesapeake and Potomac Telephone Company, Washington, D. C.
Koch, T. J., Picker X-Ray Corporation, New York, N. Y.
Lewinson, L. J. (Member), Electrical Testing Laboratories, New York, N. Y.
Lewis, B. F., Bell Telephone Laboratories, New York, N. Y.
Lynn, C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Lutz, S. G., Southern Methodist University, Dallas, Texas.
MacDonald, C., General Electric Company, Erie, Pa.
McCoy, R. R., 523 N. E. Monroe Street, Portland, Ore.
Meyer, C. A., Public Utilities Engineering and Service Corporation, Chicago, Ill.
Mier, W. A., Southwestern Bell Telephone Company, Oklahoma City, Okla.
Miller, C. F. (Member), Sun Oil Company, Philadelphia, Pa.
Mitchell, E. N., West Texas Utilities Company, Abilene, Texas.
Morgan, J. F., Mercury Mills Limited, Hamilton, Ont., Canada.
Nommesen, N. C., Hickok Electrical Instrument Company, Cleveland, Ohio.
Notley, J. A., Eastbay Transit Company, Oakland, Calif.
Odrzwolski, S. W., Bethlehem Steel Company, Buffalo, N. Y.
Paulsen, K., Langley Manufacturing Company, Granville Island, Vancouver, B. C., Canada.
Peddicord, H. R., The Chesapeake and Potomac Company, Washington, D. C.
Perry, R. H., Commonwealth Edison Company, Chicago, Ill.
Peteet, W. D. (Member), Copper Wire Engineering Association, Washington, D. C.
Reichard, W. C. (Member), American Telephone and Telegraph Company, Netcong, N. J.
Rogers, E. W., Dallas Power and Light Company, Dallas, Texas.
Schmidt, E. A. (Member) I-T-E Circuit Breaker Company, St. Louis, Mo.
Sharp, J. V., Sharp Electric Company, Salt Lake City, Utah.
Stephens, E. H., Westinghouse Electric and Manufacturing Company, Wichita, Kans.
Stiles, J. L., Clarkson College, Potsdam, N. Y.
Summers, E. R., General Electric Company, Schenectady, N. Y.
Thoman, J. S., Duquesne Light Company, Pittsburgh, Pa.
Thornton, H. N., New England Telephone and Telegraph Company, Boston, Mass.
Wadsworth, P. P., Jr., Department of Water and Power, Los Angeles, Calif.
Whitaker, D. W. (Member), West Texas Utilities Company, Abilene, Texas.
Whitmer, E. W., American Gas and Electric Service Corporation, New York, N. Y.
Wildman, J. R., Hickok Electrical Instrument Company, Cleveland, Ohio.
Yenawine, P. L., Department of Water and Power, City of Los Angeles, Calif.
Young, R. A. (Member), Condon and Young, Inc., Los Angeles, Calif.

Total, United States and Canada—69

Elsewhere

de Azevedo, F. F., São Paulo Tramway, Light and Power Company, Ltd., São Paulo, Brazil.
Edwards, G. R. T. (Member), Rangoon Electric Tramway and Supply Company, Ltd., Rangoon, Burma.
Foong, C., Sultan Abdul Hamid College, Alor Star, Kedah, Federated Malay States.
Muir Hunter, C. J. (Member), Callender's Cable and Construction Company, Ltd., Fort Bombay, India.
Vowels, R. E., Hydro-Electric Commission, Tasmania, Australia.
Sims, E. B., Tropical Oil Company, El Centro, Colombia.

Total elsewhere—6

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Society Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

Great Britain. Mines Dept. COAL MINES ACT, 1911. GENERAL REGULATIONS as to the INSTALLATION and USE of ELECTRICITY with Explanatory Notes. London, His Majesty's Stationery Office, 1938. 69 pages, diagrams, 10 by 6 inches, paper, 1s. (obtainable from British Library of Information, 270 Madison Ave., New York, $0.35). Contains instructions as to the kind, care and treatment, installation, and application of materials and equipment for electrical purposes, as set forth under the "Coal Mines Act."

RADIO, a Study of First Principles for Schools, Evening Classes and Home Study. By E. E. Burns. Third edition. New York, D. Van Nostrand Company, 1938. 293 pages, illustrated, 8 by 6 inches, cloth, $2.00. Based upon material used in teaching boys of high school age. Aims to present the fundamental principles of electricity as applied in radio as simply and clearly as possible, as a basis for further theoretical and practical study.

RECHNERISCHE VERFAHREN zur HARMONISCHEN ANALYSE und SYNTHESE. By A. Hussmann. Berlin, J. Springer, 1938. 28 pages, diagrams, charts, tables, 12 by 8 inches, paper, 9.60 rm. Intended to facilitate the use of Runge's method of harmonic analysis and harmonic synthesis by providing schedules giving greater exactness. Schedules with 12, 24, 36 and 72 points are provided. Explains the general principles of harmonic analysis and synthesis, the development of the methods of calculation, and the schedule method.

(The) ROLE of SCIENTIFIC SOCIETIES in the SEVENTEENTH CENTURY. By M. Ornstein. Chicago, University of Chicago Press, 1938. 308 pages, illustrated, 9 by 6 inches, cardboard, $3.00. Calls attention to the ways in which scientific development was aided by the scientific societies of the seventeenth century. Contains accounts of the work of many famous scientists of the period and a description of the scientific work of the universities.

(Der) SCHUTZBEREICH von BLITZABLEITERN, Neue Regeln für den Bau von Blitz-Fangvorrichtungen. By A. Schwaiger. Munich and Berlin, R. Oldenbourg, 1938. 115 pages, diagrams, charts, tables, 9 by 6 inches, paper, 5 rm. A discussion of lightning conductors and of their effective protective range under various conditions. Using the laws of high-voltage phenomena as a basis the author has devised rules for the protection of buildings and transmission lines.

(A) SELECT BIBLIOGRAPHY on the LOCATION of INDUSTRY (Social Research Bulletin No. 2). By D. M. McDonald. Montreal, Canada, McGill University, 1937. 84 pages, 10 by 7 inches, paper, $0.60 + 10c postage. A list of some 700 references to books, reports, and magazine articles grouped under four heads: general references; industrial location; industrial and economic surveys; statistical, bibliographical, and other sources.

La MAISON INSONORE. By V. Gavronsky, T. Kahan and M. Blumenthal. Paris, Dunod, 1938. 119 pages, illustrated, 9 by 6 inches, paper, 38 frs. A translation of "Das laermfreie Wohnhaus," issued by the antinoise technical commission of the Society of German Engineers. Affords a description of the effect of noise upon human beings, of methods of measuring noise, and of practical methods of insulating buildings and machines.

TELEVISION, a Struggle for Power. By F. C. Waldrop and J. Borkin, with an introduction by G. H. Payne. New York, William Morrow and Company, 1938. 299 pages, 9 by 6 inches, cloth, $2.75. Television may be expected to have profound social and political effects, and its control is of great public concern. This book discusses modern communication through the cinema, radio, and television, and calls attention to the need for a definite public policy.

ELECTRO-PLATING, a Survey of Modern Practice including Nickel, Zinc, Cadmium, Chromium, and the Analysis of Solutions. By S. Field and A. D. Weill. Third edition, revised, London, Sir Isaac Pitman and Sons, Ltd.; New York, Pitman Publishing Corporation, 1938. 381 pages, illustrated, 8 by 5 inches, cloth, $4.00. Intended to provide the electroplater with a practical account of recent advances in the art.

STRENGTH of MATERIALS. By N. C. Riggs and M. M. Frocht. New York, Ronald Press Company, 1938. 432 pages, illustrated, 9 by 6 inches, cloth, $3.75. Intended for use in a first course in the subject and is designed for students with a knowledge of the calculus and the fundamentals of statics.

Engineering Societies Library

39 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Transactions

Papers and Discussions Comprising Pages 613–62 of the 1938 Volume

Noise Co-ordination of Rural Power and Telephone Systems

By H. W. WAHLQUIST
MEMBER AIEE

T. A. TAYLOR
MEMBER AIEE

THE co-ordination of telephone and power systems has been studied for about 15 years under the auspices of the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell Telephone System. Until 1935 the noise frequency studies on distribution systems related chiefly to the types of systems employed in urban and suburban areas.[1] Between 1935 and 1937, the work was extended to include rural power and telephone systems, which differ in several respects from the systems employed in urban areas. Measurements of power circuit influence and telephone circuit noise were made on a number of representative rural systems in Nebraska, Iowa, Michigan, Ohio, Indiana, and Virginia, with the co-operation of the operating companies. These tests were supplemented by a theoretical analysis of the problem.

The investigation of the joint subcommittee indicates that it is generally practicable to secure satisfactory co-ordination of power and telephone facilities in rural areas from the ncise standpoint with the types of power and telephone systems ordinarily employed when the inductive influence of the power circuits and the inductive susceptiveness of the telephone circuits are properly controlled. Such control of influence and susceptiveness includes the following:

1. Maintenance of relatively good voltage wave shape on the power system (i.e., harmonics arising in generators, transformers, and loads confined to relatively small magnitudes).

Paper number 38-76, recommended by the AIEE committees on power transmission and distribution and communication, and presented at the AIEE summer convention, Washington, D. C., June 20–24, 1938. Manuscript submitted April 28, 1938; made available for preprinting May 31, 1938.

H. W. WAHLQUIST is assistant engineer, Edison Electric Institute, New York, N. Y.; T. A. TAYLOR is a member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y.

1. For all numbered references, see list at end of paper.

2. Suitable distribution of the loads and lengths of single-phase branches among the phases of three-phase power circuits.

3. Use of metallic telephone circuits with series and shunt unbalances to ground maintained within reasonable limits.

4. Suitable transposition of the telephone wires with respect to the power line.

5. Use of the higher impedance type of ringers where grounded ringers are required for party line service.

In particular cases, special co-ordinative measures may need to be employed in order to secure satisfactory conditions. The purpose of this paper is to discuss the factors affecting the inductive influence of rural power circuits and the inductive susceptiveness of rural telephone circuits. A summary is included of the more promising co-ordinative measures at present available for use in particular situations where such may be required. No attempt is made to present the large body of experimental and theoretical material which has been collected during this study, since this is available in other publications.[2]

The types of power distribution circuits usually encountered in rural areas are illustrated in figure 1, with the types of three-phase main lines and single-phase extensions indicated separately. A distinction is made between single-phase extensions directly connected to three-phase systems and those supplied through a step-down or step-up transformer. The latter arrangement is frequently used to provide an extension of different type or voltage from an existing system. In the systems tested during this study, these single-phase supply transformers ranged in capacity from 15 to 100 kva. In some cases, three-phase rural distribution systems serve also as lower voltage transmission systems supplying power to small towns in which a lower primary voltage is used.

The power distribution circuits in urban or suburban areas are generally relatively short and operate at high load densities. In rural areas, however, the distribution circuits tend to be longer and to operate at lighter load densities. On rural lines, therefore, harmonic charging currents and propagation effects, which are usually negligible in urban areas, may become of primary importance. The connected capacity of single-phase load transformers on the circuits tested ranged between 2 and 20 kva per mile of circuit. The lengths of the three-phase circuits tested ranged up to 65 miles, and individual single-phase extensions as long as 30 miles were encountered.

The inductive influence of a power system from a noise standpoint is determined by the magnitudes of the balanced and residual harmonic voltages and currents existing at various points. That portion of the harmonic residual current which returns in a path remote from the line conductors is often termed the "ground-return" current. The telephone influence factor (*T.I.F.*) of a power system current or voltage[3,4] in an inductive exposure is used as an index of the influence of that particular current or voltage on the noise-frequency induction in the exposed telephone circuits. It is the usual practice to express the influence of a current in terms of the product of its magnitude in amperes times its *T.I.F.*, this product being abbreviated as $I \cdot T$. Similarly the influence of a voltage is expressed as the product of its magnitude in kilovolts times its *T.I.F.*, this quantity being abbreviated as $K_V \cdot T$. These terms are used in this paper to express the influence of the balanced and ground-return currents, and balanced and residual voltages of rural power circuits.

Co-ordinated tests in exposure sections at roadway separations have shown that ground-return harmonic currents and harmonic residual voltages are generally the controlling factors in the influence of rural distribution circuits, rather than the corresponding balanced components. In exposures to the main power line, or whenever several miles of line extend beyond the exposure, the wave shape and magnitude of the *ground-return current* ($I \cdot T$) is usually the controlling factor in the over-all influence. For exposures near the end of a main line, or at any

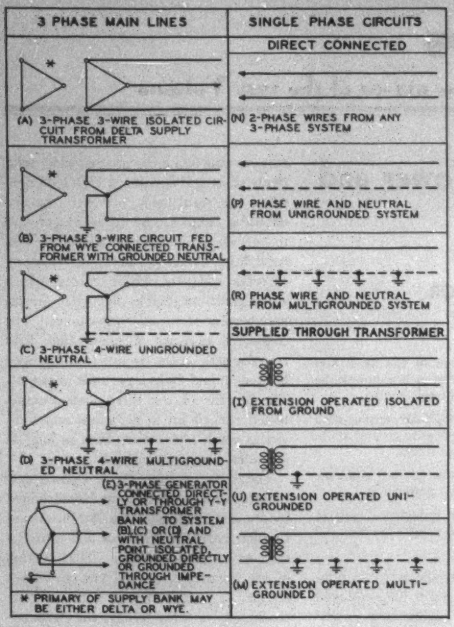

3 PHASE MAIN LINES
SINGLE PHASE CIRCUITS
DIRECT CONNECTED
(A) 3-PHASE 3-WIRE ISOLATED CIRCUIT FROM DELTA SUPPLY TRANSFORMER
(N) 2-PHASE WIRES FROM ANY 3-PHASE SYSTEM
(B) 3-PHASE 3-WIRE CIRCUIT FED FROM WYE CONNECTED TRANSFORMER WITH GROUNDED NEUTRAL
(P) PHASE WIRE AND NEUTRAL FROM UNIGROUNDED SYSTEM
(R) PHASE WIRE AND NEUTRAL FROM MULTIGROUNDED SYSTEM
SUPPLIED THROUGH TRANSFORMER
(C) 3-PHASE 4-WIRE UNIGROUNDED NEUTRAL
(I) EXTENSION OPERATED ISOLATED FROM GROUND
(D) 3-PHASE 4-WIRE MULTIGROUNDED NEUTRAL
(E) 3-PHASE GENERATOR CONNECTED DIRECTLY OR THROUGH Y-Y TRANSFORMER BANK TO SYSTEM (B),(C) OR (D) AND WITH NEUTRAL POINT ISOLATED, GROUNDED DIRECTLY OR GROUNDED THROUGH IMPEDANCE
(U) EXTENSION OPERATED UNIGROUNDED
(M) EXTENSION OPERATED MULTIGROUNDED
* PRIMARY OF SUPPLY BANK MAY BE EITHER DELTA OR WYE.

Figure 1. Types of rural power distribution systems

point along a short single-phase extension, the wave shape and magnitude of the *residual voltage* ($Kv \cdot T$) is usually the most important factor. Therefore, these residual components are of chief interest in any discussion of the influence of rural power circuits.

Residual Harmonic Voltages

Residual voltages appear on three-phase power systems operated isolated from ground (figure 1*A*) as a result of the action of the balanced voltages on the unbalanced impedances-to-ground of the phase conductors. These impedances depend chiefly upon the length of circuit connected to each phase. Consequently, the residual voltages on a three-phase isolated system tend to be least when equal lengths of extensions are connected to each phase. Practically no residual voltage exists on a single-phase circuit supplied through a single-phase transformer and operated isolated from ground (figure 1*I*).

On three-phase systems operated with grounded neutral, residual harmonic voltages may either (1) be impressed directly upon the system, as in the case of triple harmonic voltages arising in direct-connected generators or a wye-wye transformer bank without tertiary delta, or (2) arise as a result of the action of balanced voltages upon unequal impedances-to-ground of the line conductors or connected loads. On single-phase extensions consisting of a phase wire and multi-grounded neutral, the residual voltage is substantially equal to the phase-to-neutral voltage, since the neutral is at ground potential. The same is true of a unigrounded extension at the point where the neutral is grounded. However at points remote from the grounding point, the harmonic voltage from the neutral wire to ground may be comparable with the harmonic voltage from the phase wire to ground. The vector sum of the two voltages-to-ground (residual voltage) may therefore be considerably different from the voltage between the phase and neutral wires.

The range of residual $Kv \cdot T$ measured on various types of rural power circuits, in relation to the corresponding phase-to-ground $Kv \cdot T$, is indicated in table I.

Ground-Return Harmonic Currents

The components which may contribute to the ground-return current ($I \cdot T$) in a rural power line may be conveniently classified as:

(*a*) Harmonic charging currents.

(*b*) Harmonic components of the load current.

(*c*) Harmonic exciting current components arising in transformers and harmonics originating in connected loads.

The equivalent circuits of figure 2 illustrate the behavior of these three components on different types of single-phase lines. In the case of circuits 2*A* and 2*B*, the ground-return $I \cdot T$ is practically all

Table I. Summary of Influence of Rural Power Circuit Voltages

Type of Power Circuit	Number Cases Tested	Voltage T.I.F. Avg.	Voltage T.I.F. Min.	Voltage T.I.F. Max.	Phase-to-Ground Kv·T Avg.	Phase-to-Ground Kv·T Min.	Phase-to-Ground Kv·T Max.	Ratio Avg.	Res. Kv·T Ph-Gnd Kv·T Min.	Res. Kv·T Ph-Gnd Kv·T Max.
Three phase—11-13 kv										
Three-wire delta	1	13			87			0.14		
Four-wire-uni—from Δ-Y banks	7	17	7	36	124	55	250	1.1	0.16	2.1
Four-wire-uni—from direct connected generator	8	13	6	24	95	50	170	1.7	1.3	2.2
Four-wire-multi—from Δ-Y banks	12	21	8	62	151	60	450	0.9	0.4	1.8
Four-wire-multi—from direct connected generator	9	14	9	19	106	70	150	1.8	0.92	2.13
Single phase directly connected to three phase										
11 kv Delta	2	20	15	24	127	95	159	0.71	0.47	0.95
7.6 kv Delta	1	12			50			0.74		
Uni	4	17	14	22	128	110	165	1.03	1.0	1.08
Multi	4	17	11	27	129	85	210	1.0	1.0	1.0
2.3 kv Delta	3	26	8	40	36	11	55	0.49	0.40	0.62
Uni	3	19	16	23	46	39	56	1.0	1.0	1.0
Multi	4	21	19	23	49	46	56	1.0	1.0	1.0
Single phase supplied through transformer										
6.9-7.2 kv Isolated	1	17			56			0.006		
Uni	8	39	16	92	276	105	660	1.0	1.0	1.0
Multi	11	34	12	104	246	83	750	1.0	1.0	1.0
4.8 kv Isolated	2	37	35	38	88	85	90	0.034	0.034	0.036
Uni	3	40	13	57	191	64	280	1.02	0.95	1.06
Multi	8	53	11	172	258	50	830	1.0	1.0	1.0
2.4 kv Isolated	2	40	35	45	46	40	52	0.017	0.015	0.02
Uni	2	37	30	44	90	72	108	0.97	1.0	0.93
Multi	3	40	13	55	93	30	130	1.0	1.0	1.0

due to charging current, the load and exciting currents being confined to the line wires. The charging current is a function of the residual voltage impressed on the circuit and the impedance-to-ground, which in turn is dependent on the extent of the system. The impedance-to-ground of these systems is not affected by loads, although the voltage wave shape of the system may be modified by the presence of load, or harmonics generated in loads.

In the case of the multigrounded circuit (figure 2*C*), the ground-return $I \cdot T$ is contributed to by harmonic components of (1) ground-return charging currents, (2) load currents, and (3) transformer exciting currents.

The magnitude of the ground-return charging current component at any frequency depends upon the voltage impressed on the ground-return circuit and on the impedance-to-ground[2] of the circuit, neglecting loads, as seen from the point where the voltage is impressed. Sample curves of the calculated impedance-to-ground of a single-phase line are given in figure 3, showing the effect of frequency and circuit length. The maximum current results when the circuit length is such that series resonance (quarter wave length) occurs at the particular frequency in question. The higher the frequency, the shorter will be the circuit length for which resonance occurs.

Comparing the curves of figure 3 for the multigrounded and unigrounded condition, it appears that the impedance-to-ground of the *shorter* multigrounded circuits (i.e., less than quarter wave length) is higher than that of the comparable unigrounded circuit at any given frequency. This is one reason for the decrease in the ground-return charging current which often results when a circuit is converted from unigrounded to multigrounded operation. An additional effect results from the reactive component of the load current, which combines with the charging current at such an angle that further reduction in the ground-return current may result in the multigrounded case. In cases where the conversion results in changes in the residual voltage, or where the system is extensive (between quarter and half wave length), the change from uni- to multigrounded operation may either decrease or increase the ground-return charging current at a particular frequency.

As indicated in figure 2*C*, on a *multigrounded* circuit the loads are in parallel with the capacitance-to-ground and the ground-return components of the load and transformer exciting currents, therefore, add vectorially to the ground-return harmonic charging currents. In the case of multigrounded single-phase circuits having phase and neutral wires of the same size and material and of the usual configurations, about 60 per cent of the phase current returns through the earth and the remaining 40 per cent in the neutral wire. This division holds for the charging current as well as for the load and exciting components.

In the single-phase unigrounded line, large phase displacements occur between the phase wire, neutral wire, and ground-return currents. Consequently the ground-return $I \cdot T$ expressed in per cent of the phase $I \cdot T$ may range from about 40 to well over 100 per cent. For the fundamental frequency and the lower harmonics, the percentage of phase current returning in the ground is smaller in the unigrounded than in the multigrounded circuit.

Table II summarizes the average exciting ground-return $I \cdot T$ and the individual ground-return current components at 180, 300, and 420 cycles per kilovolt-ampere of connected trans-

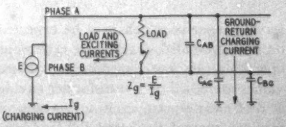
Table II. Average Ground-Return I·T and 180, 300, and 420-Cycle Currents in Single-Phase Multigrounded Circuits Due to Transformer Exciting Current

Primary Voltage	Primary Ground-Return* I·T and Mils in Ground Per Kilovolt-ampere of Connected Single-Phase Transformer			
	I·T	Mils, 180 Cycles	Mils, 300 Cycles	Mils, 420 Cycles
2,400	0.6	5.0	1.3	0.3
4,800	0.3	2.5	0.6	0.15
6,900–7,600	0.2	1.7	0.4	0.10

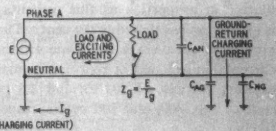
* These ground-return values are taken as 60 per cent of the phase values.

Table III. Summary of Influence of Rural Power Circuit Currents

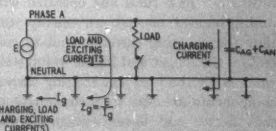
Type of Power Circuit	Number Cases Tested	Voltage T.I.F. Avg.	Min.	Max.	Phase I·T Product Avg.	Min.	Max.	Ratio Gnd. Ret. I·T / Phase I·T Avg.	Min.	Max.
Three phase—11-13 kv										
Three-wire delta	4	13			220	100	320	0.55	0.16	0.80
Four-wire-uni—from Δ-Y banks	7	17	7	36	400	40	790	0.42	0.16	0.92
Four-wire-uni—from direct connected generator	9	13	6	24	430	60	650	0.79	0.34	1.17
Four-wire-multi — from Δ-Y banks	12	21	8	62	515	40	1730	0.36	0.10	0.81
Four-wire-multi — from direct connected generators	9	14	9	19	470	60	820	0.6	0.51	0.83
Single phase directly connected to three phase										
7.2–7.6 kv Delta	1	12			110			0.41		
Uni	4	17	14	22	170	45	250	0.82	0.78	0.86
Multi	4	17	11	27	170	40	250	0.62	0.58	0.64
2.3 kv Delta	3	26	8	40	175	38	400	0.09	0.07	0.11
Uni	3	19	16	23	72	7	140	0.44	0.39	0.50
Multi	4	21	19	23	90	7	175	0.51	0.43	0.62
Single phase supplied through transformer										
6.9–7.2 kv Isolated	1	17			160			0+		
Uni	9	39	16	92	106	23	350	0.75	0.28	0.94
Multi	12	34	12	104	143	30	535	0.61	0.50	0.65
4.8 kv Isolated	2	37	35	38	170	50	290	0+	0+	0+
Uni	3	40	13	57	215	80	430	0.82	0.63	0.96
Multi	10	53	11	172	146	32	560	0.60	0.50	0.70
2.4 kv Isolated	2	40	35	45	200	110	285	0+	0+	0+
Uni	2	37	30	44	245	130	360	0.30	0.28	0.31
Multi	3	40	13	55	240	85	480	0.60	0.49	0.69



(*A*) Circuit consisting of two phase wires



(*B*) Circuit consisting of one phase wire and unigrounded neutral



(*C*) Circuit consisting of one phase wire and multigrounded neutral

Figure 2. Schematic circuits of single-phase rural power lines

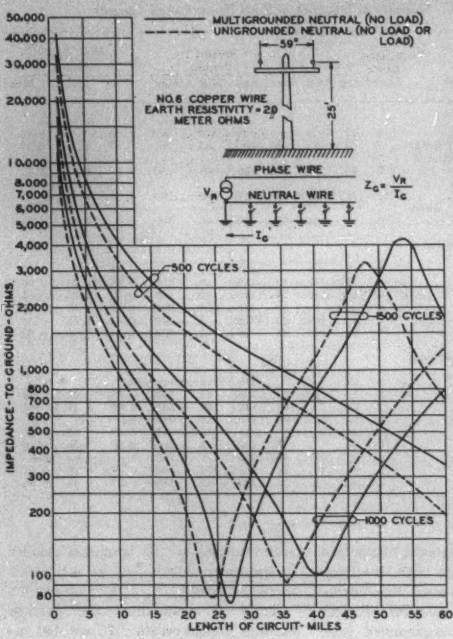


Figure 3. Impedance-to-ground of single-phase power line

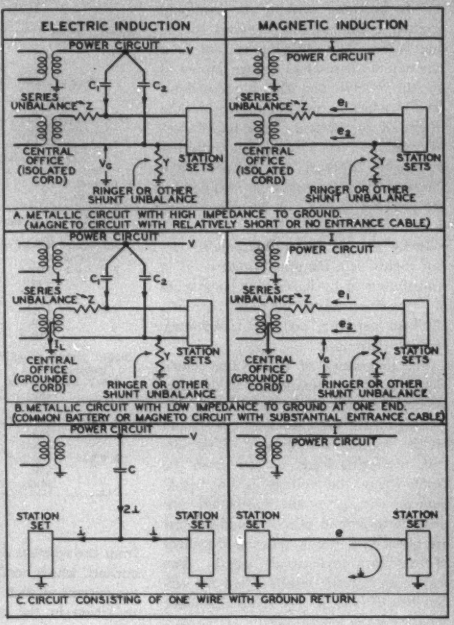

ELECTRIC INDUCTION
MAGNETIC INDUCTION
POWER CIRCUIT
SERIES UNBALANCE
CENTRAL OFFICE (ISOLATED CORD)
STATION SETS
RINGER OR OTHER SHUNT UNBALANCE
A. METALLIC CIRCUIT WITH HIGH IMPEDANCE TO GROUND. (MAGNETO CIRCUIT WITH RELATIVELY SHORT OR NO ENTRANCE CABLE)
CENTRAL OFFICE (GROUNDED CORD)
B. METALLIC CIRCUIT WITH LOW IMPEDANCE TO GROUND AT ONE END. (COMMON BATTERY OR MAGNETO CIRCUIT WITH SUBSTANTIAL ENTRANCE CABLE)
STATION SET
C. CIRCUIT CONSISTING OF ONE WIRE WITH GROUND RETURN

Figure 4. Schematic diagrams illustrating induction and susceptiveness of rural telephone circuits

former capacity which may be expected on multigrounded single-phase extensions operating at various voltages. These values are based on a transformer having a root-mean-square exciting current of five per cent of the rated full-load current, and increase or decrease approximately in proportion as this percentage is greater or less than five per cent. They are based on average harmonic exciting currents, in per cent of root-mean-square exciting current, of 40, 10, and 2.5 per cent at 180, 300, and 420 cycles, respectively.

The relative magnitudes of the three components contributing to the ground-return $I \cdot T$ of a rural line operated with multigrounded neutral are usually such that the charging currents tend to control on the longer and higher voltage circuits, while the load and exciting current components are apt to predominate on the shorter and lower voltage circuits. For a given impressed residual voltage, the ground-return charging current of a circuit operated with multigrounded neutral is usually somewhat less than that of the same circuit operated ungrounded. Consequently, where the charging current is controlling in the multigrounded case, the inductive influence tends to be less for multigrounded neutral than for isolated or unigrounded neutral operation. Conversely, where load and exciting currents become the controlling factors under the multigrounded neutral condition, the influence is usually greater for multigrounded operation.

The range of ground-return $I \cdot T$ observed on a number of rural lines of various voltages and types is indicated in table III. In this table the ground-return $I \cdot T$ is expressed in terms of the corresponding phase $I \cdot T$. The range of phase $I \cdot T$ and voltage *T.I.F.* observed in the various systems is also given for reference.

Comparison of Influence of Different Types of Systems

The relative influence under average wave shape conditions of different neutral grounding arrangements for systems of a given voltage class may be summarized as follows:

(1) Three-Phase Systems

In the *6.9 to 13.2-kv voltage range* the inductive influence of an extensive three-phase four-wire rural distribution system with metallically connected single-phase extensions is on the average, about the same for either multigrounded or unigrounded neutral operation. In this voltage range, the influence of the three-phase three-wire delta circuits tested was within the limits observed on multigrounded and unigrounded neutral four-wire systems.

In the *2.3 to 4-kv voltage range* the inductive influence of four-wire multigrounded neutral rural systems is generally somewhat higher than that of four-wire unigrounded or three-wire systems.

(2) Single-Phase Extensions

In the *7-kv class* single-phase extensions connected either metallically or through transformers have a somewhat lower influence for multigrounded neutral operation than for unigrounded operation. Extensions consisting of two-phase wires metallically connected to a three-wire system have an influence comparable to the unigrounded extension.

Extensions in the *4.8-kv class* have generally about the same influence whether operated unigrounded or multigrounded.

In the *2.3-kv class* the influence of multigrounded neutral extensions is generally greater than for those operated unigrounded.

In all voltage classes, extensions supplied

through single-phase transformers and operated isolated from ground have a very much lower influence than those operated unigrounded or multigrounded.

It is difficult to make similar comparisons between systems operating in different voltage classes because the different voltage classes tend to have somewhat different fields of application, resulting in differences in line length and load density.

Characteristics of Rural Telephone Circuits

Most of the telephone circuits used in rural areas are of the magneto type, although some common battery lines are encountered. From the noise co-ordination standpoint, there is one fundamental difference between the magneto circuit and the common battery circuit in that the former is generally ungrounded at the central office end, while the latter is grounded through the central office cord circuit. The significance of this difference will be brought out in the brief summary, given below, of the processes by which noise induction takes place. For the sake of simplicity, this discussion is confined to electrically short lines.

Schematic diagrams illustrating (*A*) an exposed metallic telephone circuit having a high impedance-to-ground and (*B*) a similarly exposed circuit operated with a low impedance-to-ground, are shown in figure 4.

Electric induction appears as a noise potential (V_g in figure 4*A*) between the exposed telephone conductors and ground. This potential is a function of the harmonic voltages on the power conductors, the mutual capacitances C_1 and C_2, and the impedance-to-ground of the telephone circuit. In the case of a telephone circuit isolated from ground, as in figure 4*A*, the noise potential to ground tends to be relatively high, the noise current flowing to ground through the capacitance-to-ground of the circuit. Where one end of the telephone circuit is grounded, as through the cord circuit on a common battery line (figure 4*B*) or through the capacitance-to-ground of an appreciable length of entrance cable, the noise potential to ground due to electric induction may become very small. In this case a noise current (I_L) flows over the two conductors in parallel toward the low-impedance ground.

Magnetic induction appears as a noise voltage (e_1 and e_2, figure 4*A*) acting in the longitudinal circuit of the telephone line. The induced voltage is a function of the harmonic currents in the power line and mutual inductance between the power and telephone conductors. The impedance of the telephone longitudinal circuit controls the magnitude of the resulting longitudinal current. Where the impedance-to-ground is high, as in figure 4*A*, the magnetically induced voltage-to-ground divides between the two ends of the circuit roughly in proportion to their impedances-to-ground. Where one end of the circuit is grounded, the entire induced voltage appears at the other end.

In the case of electric induction, differences in the capacitances C_1 and C_2 result in a difference of potential between the two telephone conductors, thus giving rise to a metallic-circuit noise current known as the "direct metallic" induction. Differences between the magnetically induced voltages e_1 and e_2 similarly result in a "direct metallic" component of magnetic induction. Telephone circuit transpositions tend to equalize the capacitances C_1 and C_2 and the voltages e_1 and e_2 and may thus greatly reduce the noise due to "direct metallic induction."

In the case of a ground-return circuit (figure 4*C*) the current-to-ground due to electric induction (i) flows directly through the station sets, while the voltage due to magnetic induction (e) acts on a longitudinal circuit which includes the impedances of the station sets. This accounts for the fact that the noise in a ground-return circuit is usually of the order of 100 times that in a reasonably well balanced metallic circuit under similar exposure conditions.

In addition to the component of noise induced directly between wires, metallic-circuit noise may also occur as a result of the action of longitudinal induction on circuit unbalances. These may be either series impedance unbalances (Z in figure 4) or shunt admittance unbalances (Y in figure 4). The more common sources of series unbalances in rural circuits are high resistance joints and certain types of switching circuits used in common battery offices. Shunt unbalances may arise as a result of contacts between line wires and trees, from faulty insulation, from the ringers associated with certain types of station sets where grounded ringing is employed, or from certain types of central office apparatus.

Considering first the effects of electric induction, in figure 4*A*, where the central office end of the circuit has a high impedance-to-ground, the voltage-to-ground appears across the shunt admittance (Y) and contributes a component of noise in the metallic circuit. In this case the effect of a series unbalance (Z) is small. However, where the circuit has a low impedance-to-ground, as in figure 4*B*, the voltage-to-ground due to electric induction is negligible, and the effect of the admittance unbalance (Y) is small. In this case, as pointed out above, the induction produces a current-to-groun d

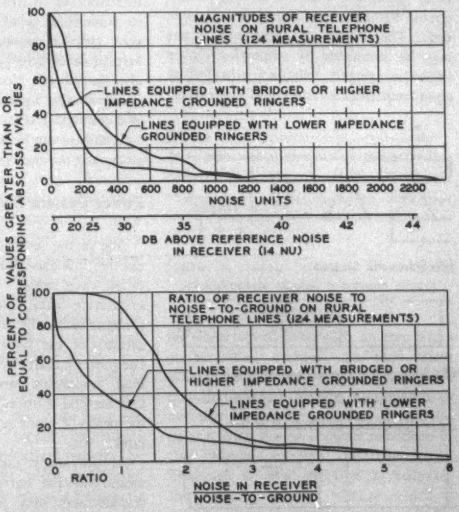
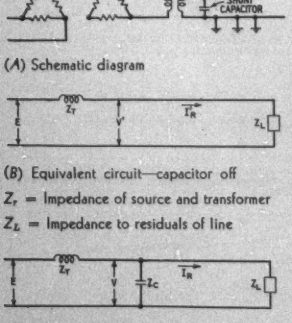

MAGNITUDES OF RECEIVER NOISE ON RURAL TELEPHONE LINES (124 MEASUREMENTS)
LINES EQUIPPED WITH BRIDGED OR HIGHER IMPEDANCE GROUNDED RINGERS
LINES EQUIPPED WITH LOWER IMPEDANCE GROUNDED RINGERS
PERCENT OF VALUES GREATER THAN OR EQUAL TO CORRESPONDING ABSCISSA VALUES
0 20 40 60 80 100
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200
NOISE UNITS
0 20 25 30 35 40 42 44
DB ABOVE REFERENCE NOISE IN RECEIVER (14 NU)
RATIO OF RECEIVER NOISE TO NOISE-TO-GROUND ON RURAL TELEPHONE LINES (124 MEASUREMENTS)
LINES EQUIPPED WITH BRIDGED OR HIGHER IMPEDANCE GROUNDED RINGERS
LINES EQUIPPED WITH LOWER IMPEDANCE GROUNDED RINGERS
0 1 2 3 4 5 6
RATIO
NOISE IN RECEIVER / NOISE-TO-GROUND

Figure 5. Noise measured on magneto telephone subscriber circuits in rural areas

and this current acts upon the series unbalance (Z) to produce a metallic-circuit current.

In the case of magnetic induction, the full longitudinal voltage appears across the admittance unbalance (Y) when the circuit is grounded at the central office (figure 4B). If Y is relatively small, the longitudinal current will be relatively small and its effect on the series unbalance (Z) is unimportant. If there is a low impedance-to-ground at each end of the circuit, the longitudinal current may be appreciable, and the effect of (Z) becomes important.

The effects of unbalances may be summarized as follows: shunt unbalances tend to be important where electric induction controls the noise in circuits operated isolated from ground, or where magnetic induction is important, particularly when the circuit is grounded at the central office and such unbalances occur near the far end of the line. Series unbalances may be important where electric induction acts on a circuit grounded at one point, or in the case where magnetic induction acts on a longitudinal circuit having a low impedance at each end. The effects of these unbalances may be minimized by employing higher impedance ringers, balanced central office equipment, and by reasonably adequate



(*A*) Schematic diagram

(*B*) Equivalent circuit—capacitor off

Z_T = Impedance of source and transformer

Z_L = Impedance to residuals of line

(*C*) Equivalent circuit—capacitor on

Figure 6. Shunt capacitors for improving wave shape of rural power lines

maintenance of the open-wire circuits. In some cases special measures, discussed below, may be employed.

The cumulative per cent curves in the upper portion of figure 5 indicate the range of noise observed on a large number of rural magneto telephone circuits exposed to various types of power circuits. No attempt is made to differentiate between the effects of the different types of power systems involved. An indication of the relative influence of these different types of system may be obtained from tables I and III. The effects of the lower impedance ringers in increasing the receiver noise are indicated in figure 5.

The ratio of receiver noise to noise-to-ground (noise current to ground through 100,000 ohms) is frequently used as an index of the balance of a telephone circuit. This quantity has been calculated for the rural circuits tested and the results are plotted in the lower portion of figure 5.

Co-ordinative Measures

Co-operative planning by those responsible for the development and operation of power and telephone systems is important in rural areas as well as in urban and suburban areas.[1] The general co-ordinative measures outlined in the introduction to this paper are discussed in somewhat more detail below. Certain specific measures which may be helpful in certain types of situation are also described. None of these measures is universally applicable. The measure or combination of measures best suited to a given case can be determined only when all the various factors are known.

Power System Measures

One of the factors controlling the inductive influence of a rural power circuit is its wave shape. The problem of co-ordinating rural power and telephone systems is usually simplified if the magnitudes of the harmonics impressed on the power circuits by either the supply or load apparatus are relatively small. One method of improving the wave shape, by means of shunt capacitors, is discussed later.

As previously pointed out, the harmonic exciting currents of single-phase transformers may be of importance in the inductive influence of multigrounded distribution circuits, particularly those operating in the lower voltage ranges. The magnitudes of these harmonic components can be controlled to a considerable extent in both the design and application of the transformers. Tests indicate that there is a rapid increase in the harmonic components of the exciting current of a transformer when the rated fundamental frequency voltage is exceeded. It is therefore desirable to avoid impressing excessive voltages on transformers, particularly when they are connected to the lower voltage multigrounded circuits.

On three-phase distribution systems, reductions may often be effected in the inductive influence if the lengths of single-phase extensions as well as the amounts of single-phase loads are balanced among the various phases in so far as practicable. Field experience has indicated, however, that where relatively large harmonics are present in the voltage wave shape of an extensive system, it is generally im-

Table IV. Measured Effectiveness of Shunt Capacitors in Reducing Inductive Influence of Rural Distribution Circuits Supplied from Transformers

Case A—Six-mile multigrounded 7.2-kv single-phase extension supplied through a 25-kva 2.3–6.9-kv transformer. Capacitor connected across 6.9-kv side of transformer.				
Capacitor (Kilovolt-amperes)	None		15	
Voltage *T.I.F.* 2.4 kv	20		15	
Voltage *T.I.F.* 7.2 kv	74		5.6	
Phase *I·T* of 7.2-kv extension	390		29	
Ground-return *I·T* of 7.2-kv extension	215		16	
Case B—Thirty-mile multigrounded 6.9-kv single-phase extension supplied through 100-kva 2.3–6.9-kv transformer. Capacitor connected across 6.9-kv side of transformer.				
Capacitor (Kilovolt-amperes)	None	15	20	35
Voltage *T.I.F.* 2.3 kv	76	36	16	15
Voltage *T.I.F.* 6.9 kv	118	32	30	16
Phase *I·T* of 6.9-kv extension	2,130	535	480	285
Ground-return *I·T* of 6.9-kv extension	1,120	285	260	163
Case C—Twelve-kv three-phase four-wire multigrounded system (total length 13 miles three phases and 27 miles one phase) fed from 150-kva 13.2–12-kv delta-wye transformer bank. Three-phase capacitors connected on 12-kv side of transformer.				
Capacitor (Kilovolt-amperes per phase)	None	15	30	
Average phase-phase voltage *T.I.F.* 13.2 kv	20	16	17	
Average phase-neutral voltage *T.I.F.* 12 kv	58	12	9	
Average phase *I·T*—12-kv line	610	90	50	
Ground-return *I·T*—12-kv line	360	45	30	

practicable to secure adequate reductions in the ground-return current components of a three-phase circuit by balancing the extensions only, without resorting to reductions in the impressed harmonic voltages.

Power circuit transpositions afford an effective means of reducing longitudinal induction in exposed telephone circuits only if the influence is controlled by balanced rather than residual components.[6] In rural distribution exposures the induction practically always results from residual components, and in such cases transpositions are generally ineffective. Furthermore, in the case of

three-phase circuits, these residuals are usually due either to the unequal lengths of single-phase extensions connected to the various phases or to direct-connected generators with grounded neutrals and consequently are not susceptible to reduction by transpositions.

Shunt Capacitors for Reducing Inductive Influence

Several situations have recently developed in the field in which the influence of the power lines was considerably increased by resonance between the leakage inductance of the supply transformer and the line capacitance at or near one of the harmonic frequencies present in the impressed voltage. In such cases it has been found practicable to improve wave-shape conditions by the application of shunt capacitors on the rural-line side of the supply transformer.

Figure 6*A* presents a schematic diagram of a single-phase extension supplied from a three-phase system through a single-phase transformer. Figure 6*B* is a simplified equivalent circuit of this arrangement, the voltage E representing the voltage at a given harmonic frequency in the wave shape of the source. Actually there are other harmonics in the system such as those generated by the supply and load transformers, or by certain types of load. However, on rural lines these frequently contribute less to the over-all influence than the supply system voltages and for simplicity have been omitted from the equivalent circuit.

In rural distribution lines, particularly under light load conditions, the impedance Z_L (figure 6*B*) is largely capacitive reactance below the quarter wave length frequency. Consequently, a condition of series resonance will exist at the frequency where the inductive reactance of the source and transformer (Z_T) is equal to the capacitive reactance of the line (Z_L), resulting in substantial increases in the voltages and currents in the rural line at harmonics in the vicinity of the resonant frequency. The connection of a suitable capacitor across the circuit, as indicated in figure 6*C*, will change the resonant point to some lower frequency, thus causing large reductions in those harmonics which were close to the resonant frequency existing before the capacitor was connected. In selecting[2] the size of capacitor for a particular situation it is important to avoid establishing the lower frequency resonant point close to one of the harmonic frequencies present in the voltage wave shape. The shunt capacitor in combination with the transformer leakage inductance also has a filtering action which tends to reduce the higher frequencies where the impedance of the capacitor is small in comparison with the impedance of the rural line.

The degree of improvement in influence effected by the application of a capacitor depends upon the particular harmonic frequencies present and upon such other factors as the relative size of the capacitor and transformer, the length of the rural line, and the magnitude of harmonic components originating in loads. The results of tests of the effectiveness of shunt capacitors in three field situations, the first two involving single-phase extensions and the third a three-phase line, are summarized in table IV. It will be noted that in all cases, before the capacitors were applied, the voltage *T.I.F.* was higher on the line than on the supply side of the transformer due to the resonant condition previously mentioned. Substantial reductions in both voltage *T.I.F.* and ground-return *I·T* were effected by the use of capacitors in these cases.

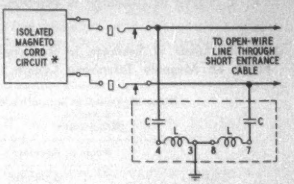
Telephone System Measures

Experience has indicated that the noise in transposed open-wire telephone circuits exposed to rural power lines at roadway separation is apt to be controlled by the action of longitudinal induction on circuit unbalances rather than by direct metallic induction. In cases where the effects of circuit unbalances have been minimized and the telephone circuit transpositions are not co-ordinated with the exposure conditions, improvements in the transposition arrangement should result in reductions in the direct metallic induction and in the receiver noise.

In general, station sets of the multiparty types on rural telephone lines are equipped with the higher impedance type of ringers, particularly where circuits are subject to noise induction. The lower impedance grounded ringer is therefore less likely to be an important factor in the co-ordination problem in rural localities than in urban areas.[1] Since unbalance of any type may contribute to the metallic circuit noise, any measures taken to improve the balance of a rural circuit will be reflected in noise reduction. In some cases the most practicable means of reducing the susceptiveness of the telephone circuits may be the application of the special measures described below.

Drainage on Ungrounded Circuits

As shown in figure 4*A*, the receiver noise on magneto lines which are ordinarily ungrounded at the central office, may be controlled by the action of voltage-to-ground from electric induction

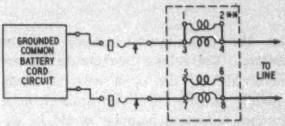


(*A*) Use of drainage on ungrounded circuits (noise controlled by action of longitudinal electric induction on shunt unbalances)

L,L—Balanced retardation coil with midpoint grounded

C,C—Capacitors of approximately one microfarad capacitance

* Drainage also applicable where line is grounded through high impedance



(*B*) Use of high impedance in longitudinal circuit (noise controlled by action of longitudinal magnetic induction on series unbalances)

** Repeating coil connected to offer high longitudinal and low metallic circuit impedance

Figure 7. Special measures for reducing susceptiveness of rural telephone circuits

on shunt unbalances such as tree leaks or grounded ringers. In such cases substantial improvement in the noise may be secured by the application of drainage at the central office end of the circuit, with the consequent reduction of the voltage-to-ground on the circuit. Drainage is also effective in reducing the 60-cycle induced voltage which is sometimes sufficiently large to cause false ringing of subscribers' bells where grounded ringers are employed. Figure 7*A* shows schematically an arrangement of a balanced retardation coil and a pair of balanced condensers for this purpose. This combination presents a low impedance to the longitudinal circuit, and a relatively high impedance across the metallic circuit. The condensers are provided to permit satisfactory ringing and d-c testing on the circuit. Since

drainage increases the longitudinal noise current, the use of this low-impedance termination may result in increased noise in cases where important *series* unbalances are present in the telephone circuit.

Where an open-wire line enters an office through an appreciable length of cable, a degree of drainage is provided by the capacitance-to-ground of the latter. Where long entrance cables are involved and the open wire is consequently already effectively drained, little further reduction in noise would be expected from the drainage scheme described above.

Table V. Effect of Drainage in Reducing Noise on Magneto Telephone Circuits

Location	Central Office Terminal*	Noise Measured at Subscriber's Location (Noise Units): Noise to Ground	Noise in Receiver: Bridged Ringer	Noise in Receiver: Grounded Lower Impedance Ringer
A	*I*	350	70	450
	G	9	0+	0+
B	*I*	400	85	500
	G	60	65	65
C	*I*	750	210	1,400
	G	15	150	170
D	*I*	210	1,100	1,130
	G	20	160	160

* *I*—Central office end isolated from ground.
G—Central office end grounded through midpoint of balanced termination (figure 7*A*).

Although primarily intended for use on magneto circuits, this drainage device may also find application on common battery circuits where noise results from the action of longitudinal induction on unbalances in the central office. In step-by-step offices, for example, where the impedance-to-ground offered by the central office equipment may be of the order of 1,000 ohms at 1,000 cycles, advantage may be taken of the relatively low impedance of the drainage device to reduce the voltage acting on central office unbalances.

The effectiveness of this drainage device in reducing the noise on magneto circuits at several locations where electric induction controlled is demonstrated by the data summarized in table V.

High Impedance in the Longitudinal Circuit

In the case of common-battery manual circuits there may be relatively large longitudinal noise current flowing to earth through the cord-circuit ground at the central office (figure 4*B*). Where *series* unbalances are present either in the line or in the cord circuit, the component of metallic-circuit noise, resulting from the action of the longitudinal current on these unbalances, may be controlling. In cases where *magnetic* induction controls, considerable reductions in the longitudinal current and consequently in the receiver noise may be effected by inserting an inductance in the circuit, as illustrated in figure 7*B*. This device is so connected as to offer a relatively high impedance to the longitudinal circuit and a very low impedance to the metallic circuit. Increasing the longitudinal circuit impedance frequently increases the noise-to-ground on the circuit. Consequently, a net improvement in the metallic-circuit noise will be obtained by this method only where the effect of *shunt* unbalances is small.

In some cases both series unbalances in office equipment and shunt unbalances on the line may be important. In such instances, use may be made of a combination of the high longitudinal impedance, inserted at the central office, and the drainage device, discussed above, the latter being connected on the line side of the series impedance.

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1. Inductive Co-ordination of Common-Neutral Power-Distribution Systems and Telephone Circuits, J. O'R. Coleman and R. F. Davis. Electrical Engineering, volume 56, January 1937, pages 17–26.

2. Engineering Report 40 of Engineering Reports of Joint Subcommittee on Development and Research.

3. Engineering Report 33 of volume IV, Engineering Reports of Joint Subcommittee on Development and Research.

4. Measurement of Telephone Noise and Power Wave Shape, J. M. Barstow, P. W. Blye, and H. E. Kent. AIEE Transactions, volume 54, 1935, page 1307.

5. Engineering Report 36 of volume IV, Engineering Reports of Joint Subcommittee on Development and Research.

Discussion

L. F. Roehmann (Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.): The authors suggest the use of shunt capacitors as a means for lowering the inductive influence of power lines. They claim two favorable effects, namely:

1. Detuning the circuit for the harmonic for which it is in resonance, and

2. Short-circuiting other harmonics.

The measurements as shown in table IV indicate that the reductions exceed the ratio 10 to 1, a very satisfactory result.

But this result is accomplished by comparatively large and expensive capacitors (15 to 35 kva), and I wonder whether such expense be justified from the standpoint of noise co-ordination alone.

The aspect becomes much more favorable, however, if the effect on the fundamental is considered too. The capacitors should improve power factor and regulation, both desirable features especially in rural electrification.

I would like to know if the authors have studied this point, and if they can confirm my considerations.

H. E. Kent (Edison Electric Institute, New York, N. Y.): The paper by Messrs. Wahlquist and Taylor has presented the rural co-ordination problem as it affects metallic telephone circuits. I should like to refer briefly to some co-ordinative measures which can be used where ground-return telephone circuits are involved. These are predominately measures applicable to the telephone system, since the measures already described for application to the power system effect approximately the same degree of reduction in influence whether metallic or ground-return telephone circuits are involved. However, it should be borne in mind that a ground-return circuit is inherently of the order of one hundred times as sensitive to induction as is a metallic telephone circuit. Consequently, while the power system measures already described greatly simplify co-ordination with metallic telephone circuits, in many situations additional measures will be required in the co-ordination of ground-return telephone circuits.

The improvement of wave shape by means of capacitors described in the paper is obtained by preventing the higher frequency harmonics in the source of supply from reaching the rural distribution system. In one of the cases where this method was applied it was found that, after the capacitors were connected at the supply substation, various small motors supplied by the rural distribution system still introduced appreciable harmonics, the effects of which were amplified by line resonance conditions. While this was not sufficient to disturb metallic telephone circuits, it resulted in appreciable noise in the ground return circuits. Application of an additional bank of capacitors to the rural circuit at a point about 20 miles from the supply substation destroyed the resonance conditions and effected further reduction in the influence.

Capacitors provide a means of largely eliminating the higher frequency harmonics in many situations, particularly in rural areas. However, it is not feasible to also reduce the lower frequency harmonics (particularly 180, 300, and 420 cycles) by this method. Where these low frequencies control it is possible to improve conditions by reducing the sensitivity of the telephone set in this low frequency range but with no important change in sensitivity over the remainder of the voice frequency range. Two methods of accomplishing this are indicated in figure 1. The commonly used connection for a local battery telephone set is shown in figure 1*A*. This is modified in figure 1*B* by shunting the receiver with an inductance of 60 millihenries and by connecting a 0.75-microfarad condenser in series with the receiver. In figure 1*C* the modification consists of transferring the receiver from the line to a location across the transmitter winding of the induction coil, and adding a one-microfarad condenser in series with the

receiver. Field tests in several locations have shown that either of these methods effects reductions in noise of somewhat better than 2 to 1 on the average when the frequencies controlling the noise are in the range from 180 to 420 cycles.

Similar results can be obtained by reducing the acoustical response of the telephone receiver at the lower frequencies. This can

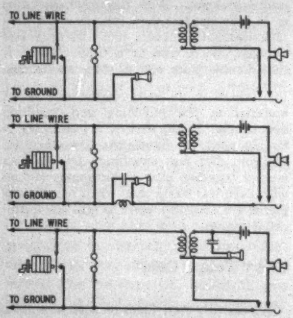

Figure 1. Schematic diagrams of commonly used and modified connections of local-battery telephone set

(*A*) Connection in common use
(*B*) Modification employing receiver filter
(*C*) Modification employing reconnection of set

be done by punching a quarter-inch hole in the receiver diaphragm at a point one-third the distance across its diameter. Tests have shown that the reduction in the low-frequency noise thus obtained is approximately the same as that secured with the electrical filters. The advantage of the acoustical method lies in its simplicity. It may have some disadvantage from a maintenance standpoint since dirt can more readily enter the space back of the diaphragm.

Figure 2 illustrates the use of a ring-through type of repeating coil in a ground-return telephone circuit to reduce noise by, in effect, transposing the circuit without materially impairing the talking and ringing efficiency of the circuit. The coil acts as a low-impedance drain from line to ground for noise currents resulting from electric induction. For magnetically induced currents the coil acts as a high impedance in series with the line. The effectiveness of the coil depends to a considerable extent on

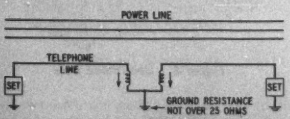

Figure 2. Use of ring-through repeating coil to reduce noise induction in ground-return telephone line

Note: Repeating coil connected as a drainage coil—that is, so as to offer low impedance to equal currents in the same direction in each winding as indicated by the arrows

having approximately equal induction in the line on both sides of the coil. In long exposures, particularly where subscribers are distributed through the exposure, more than one coil may be necessary.

In individual cases the application of capacitors for the improvement of the power system wave shape combined with a change in the frequency response of the telephone sets, or the use of repeating coils, permits the rendering of reasonably satisfactory rural telephone service over the ground-return line. However, as the load increases on the power line, and more motors are connected, it will become very difficult to maintain the extremely low influence of the power line. This, combined with greater demands made upon the telephone service, may make it impractical to render acceptable service over the ground-return line. Therefore, in applying these measures it must be recognized that in many situations they will offer only a temporary solution of the problem and that ultimately it will be necessary to "metallicize" the line. Of course, in some situations the growth of the service requirements of both the power and the telephone will be such that these measures may last for a number of years. In other situations the growth of the load will be such that continual attention will be required and "metallicizing" will necessarily follow in a very short time.

J. T. Howard (Tennessee Valley Authority, Chattanooga): The authors have touched upon two vital factors contributing to power system influence which seemingly should be given more attention for the benefit of distribution engineers. These are the ground-return harmonic components of transformer exciting currents and charging currents.

Where the rural distribution system is extensive, the voltage at the point of supply is often held 10 or 15 per cent above normal in order to obtain the desired secondary voltage at some distant point without resorting to excessive use of boosters. With distribution transformers working at high flux densities at normal voltage, this increase results in excessive magnetizing current. The net effect is an increase in the $I \cdot T$ product. While it is true, generally, that these components do not control on the larger and higher voltage circuits, many instances have been observed where their effect, in an extensive system, was the controlling factor in noise induction. It appears that placing more emphasis on this point would be of material benefit to distribution engineers, so that they may be guided accordingly in controlling system voltages, and to manufacturers, so that their transformer designs may be modified to allow a better tolerance for overvoltages.

It has been found that the most severe cases of noise induction result from harmonic charging currents, and that exposed communication circuits require a higher degree of maintenance than is customary, if the charging circuit effects are to be minimized. The effects of changes in impedance-to-ground do not seem to be generally understood by distribution engineers, and new systems are designed, and operating systems extended, without any consideration of this factor. In the case of systems operating with an $I \cdot T$ product within the range of average values, extensions may be so connected to the system that resonance occurs at a frequency with a high *T.I.F.* contribution, and the $I \cdot T$ product increases correspondingly. In such event, the distribution engineer is confronted with a difficult task in again co-ordinating his system with exposed communication facilities. It therefore seems desirable that the authors make available, in a concise form, the results of impedance-to-ground measurements which they have made during the past several years, classified as to voltage and configuration. In this manner, the problem of power system influence may be more readily understood.

H. W. Wahlquist and **T. A. Taylor:** As mentioned by Mr. Kent, the paper is confined to the rural co-ordination problem as it affects metallic telephone circuits and his discussion of several co-ordinative measures applicable to ground-return telephone circuits will no doubt be appreciated by those who are interested in this phase of the problem.

Mr. Roehmann refers to the comparatively large and expensive capacitors used in accomplishing the reductions in influence listed in table IV. While it is true that the kilovolt-amperes of the capacitors was considerable, representing about 15 to 60 per cent of the kilovolt-amperes of the supply transformer, the expense involved was found to be less than that of other co-ordinative measures of equal effectiveness. The use of such capacitors increases the 60-cycle voltage about two to 5 per cent, but has little effect on the voltage regulation of the line. In the case of a rural line having a peak load of low power factor approaching the rating of the supply transformer, the capacitors would be beneficial in reducing the load on the transformer by reducing the reactive kilovolt-ampere.

Mr. Howard feels that more emphasis should be placed on transformer exciting currents as a source of harmonics. While it is true that transformer exciting currents may control the $I \cdot T$ product on rural lines under light load conditions (in cases where the harmonics in the supply systems voltage are relatively small), the magnitude of the $I \cdot T$ product under such conditions is relatively low. On the other hand, in urban areas, transformer exciting currents have in some cases been of importance from the noise standpoint due, among other things, to the heavier load density and to different characteristics of the telephone apparatus. Mr. Howard also expresses interest in impedance-to-ground measurements on power systems. This is an important factor and has received detailed consideration. Methods have been developed for calculating this impedance and have been presented, together with measured results for a few cases, in reference 2 of the paper. Control of the *magnitude* of the impedance-to-ground by special attention to circuit layout does not appear likely to be of much practical importance because operating and service requirements will necessarily govern the system arrangement. However, as pointed out in the paper, it may be feasible to minimize the *unbalance* of the impedance-to-ground among the several phases of a three-phase system by connecting approximately equal lengths of single-phase extension to each of the three phases.

The Wound-Core Distribution Transformer

By E. D. TREANOR
MEMBER AIEE

IN THE very early days of the development of a-c transformers, various methods were tried to produce cores which would have the necessary characteristics of low loss, low magnetizing current, and suitable mechanical arrangements. It was very soon found that the most practical form of raw material was thin iron or iron-alloy sheet which could be obtained with relatively low hysteresis loss, and could be cut and assembled so as to give relatively low eddy-current loss and magnetizing current.

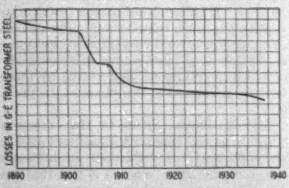

Figure 1. Improvement in hot-rolled magnetic steel

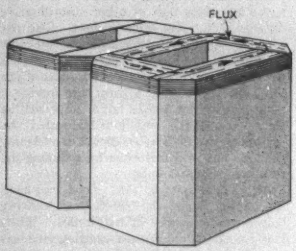

Figure 2. Shell-type core

In this form of thin sheet, magnetic steel for a-c apparatus has undergone years of intensive development from the standpoint of processing and alloying, and steady improvement has made available the silicon steel alloys of excellent characteristics which are in general use today. These are made by hot rolling in packs having maximum dimensions of about three by nine feet. A graphic history of improvement in quality is shown in figure 1.

The mechanical construction of transformer cores has almost universally continued the early practice of cutting plates or punchings from this sheet and building these pieces into massed arrangements of simple or complicated form around the coils. Characteristic examples are shown in figures 2, 3, and 4. Figure 2 shows what is usually called a shell-type core, figure 3 a "core" type, and figure 4 a modified type, which is called the distributed core.

Cores made in this general fashion have certain objectionable features.

(*a*) The pieces cannot be cut and arranged so that the flux path follows the grain orientation of the steel throughout the core and thus obtain the lowest loss possible. Reference to the sketches will show that in figure 2 and figure 3 appreciable parts of the punchings have the grain direction (shown by light lines) lying at some angle with the flux while in figure 4 practically all of the punchings show an angle between grain and flux. Some portions carry no flux at all.

(*b*) The pieces as ordinarily laid up in one or two thicknesses per layer have a minimum of two overlapped gaps in the magnetic circuit (where L punchings are used) and a maximum of four such gaps where straight plates are used. These gaps are dependent in size upon perfection of the pieces and the skill of the workmen, and at best add a little local loss due to fringing of flux and demand an appreciable magnetomotive force, or in other terms, magnetizing current.

(*c*) Large numbers of pieces must be cut and handled through various operations, such as annealing and assembly. Substantial clamping structures must also be used to hold the structure together but without undue pressure. With the usual thickness of 14 mils, not less than 140 pieces per inch of assembled thickness must be used and handled one or two at a time. There is considerable labor cost in these operations.

(*d*) There is at best considerable waste material in the punching and handling operations. In the case of L punchings so largely used on distribution transformers, multiple dies cut punchings from sheets welded together into a continuous ribbon with even less waste than when rectangular pieces are used but there is still an appreciable waste.

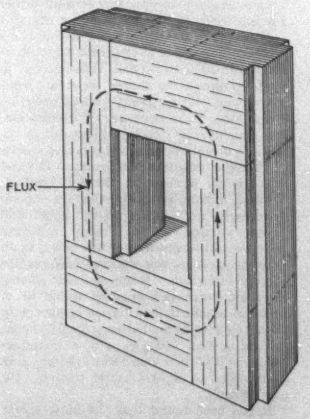

Figure 3. "Core" type core (two legs)

The "Wound Core"

A radically new form of core of simple structure and highly efficient performance has recently been developed. As shown schematically in figure 5, it is made by winding a long ribbon of magnetic steel in a tight spiral on a mandrel into the form of a heavy-walled circular cylinder. This core construction has been designated as the "wound core." It eliminates or minimizes most of the objections inherent in other types.

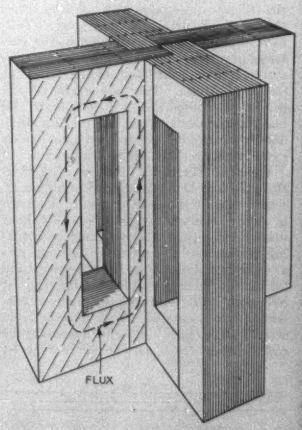

Figure 4. Distributed core

(*a*) The flux runs with the grain direction throughout. All material in the core is active material.

(*b*) There is but one effective gap in the magnetic circuit and this is of very short length and large area.

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(c) Only one or two pieces of strip steel are necessary to make the average small core. These are prewound and assembled on machines at high speed.

(d) The waste in handling and fabrication is very small since each element is simply cut from large reels of continuous strip made to correct width at the mill.

A practical core incorporating these and other advantages obviously presents a distinct advance in the design and construction of transformers to which it is applicable. It is the purpose of this paper to describe its present application to distribution transformers.

As stated above, L punchings for distribution transformers are cut from reels of steel made by welding together sheets of hot-rolled steel. Distribution transformers of the wound-core construction can utilize such hot-rolled steel with improvement in characteristics and reduction in cost over existing designs, but the wound-core construction makes it possible to take full advantage of the properties of cold-rolled strip of relatively low silicon content. This strip is characterized by high permeability and very good losses at high densities, and is nonaging. It is made by high-reduction rolling on a suitable mill and mechanically is soft and ductile when compared with high silicon hot-rolled sheet. It is produced in a strip of great length.

Figures 6 and 7 show tentative comparisons of watt loss and permeability as compared with good high-silicon hot-rolled sheet. It is strongly directional in these properties, the losses at flux

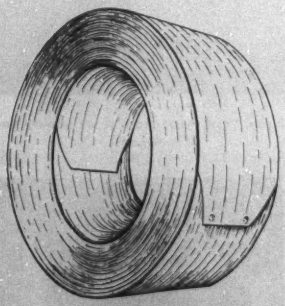

Figure 5. Wound core

angles with the grain of 45 degrees to 90 degrees being from 45 per cent to 70 per cent higher than with the grain. These properties indicate the possibility of operation at higher densities than are normal with ordinary steel, particularly in a core in which the magnetic material is worked with the grain.

Considering a core made up of single ribbon, whose grain direction runs with its length, wound into a circular cylinder and embraced by a current-carrying coil, it will be seen that the flux must follow the grain direction very closely. In such a core (figure 8), it will be seen also that each element of flux finds but one air gap in its path, and if the ribbon is tightly and uniformly wound, this gap will be of very small length and relatively great area. The result is that little magnetomotive force is consumed in the reluctance of air gaps as compared with other cores.

In the practical design of transformer cores, flux density is limited by heating or

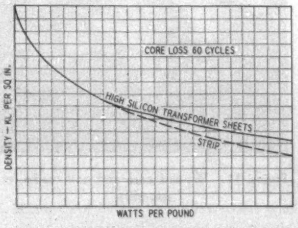

Figure 6. Watt loss of hot-rolled and new strip steel

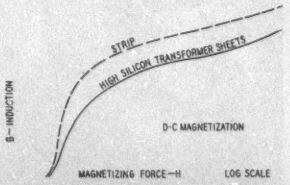

Figure 7. Permeability of hot-rolled and new strip steel

magnetizing current in large transformers and usually to still lower values by magnetizing current alone in small units. The combination of a steel having high permeability and low losses in the high density range with a core structure which reduces the number and length of air gaps promises highly effective use of material, particularly in small-sized transformers.

Designs for ratings of $1^1/_2$, 3, and 5-kva units with primary voltages of 7,620 volts or less have been worked out and placed in production, and the promise of economy has been fully realized. The most satisfactory construction consists of two core elements as shown in figures 9 and 10, linked by a simple interleaved coil group in secondary-primary-secondary arrangement. Due to the ability to work the core at higher density than is usual for small transformers, normal characteristics can be obtained with considerable economy of material and reduced over-all cost in spite of the fact

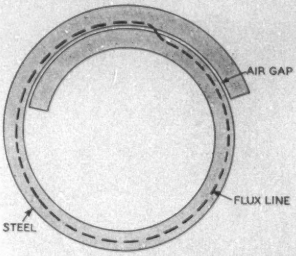

Figure 8. Path of flux in wound core

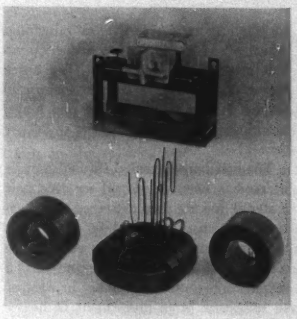

Figure 9. Core and coil elements

that the new steel is at present higher in cost than hot-rolled silicon steel.

Core Manufacture

The steel for wound cores is produced at the mill in strips of required widths and great length. These strips are slit into multiples of desired width for various size cores and are shipped in reels of a convenient size and weight to the factory. These reels are set up in multiple before a prewinding machine which consists of an accurately sized power-driven steel mandrel. The ends of the reels are attached to the mandrel which is then rotated, drawing the strips through tension devices until the cores are built up to the desired thickness which is individually controlled by micrometer gauges. Each strip is cut and temporarily welded to hold the core in shape during anneal. The whole operation is, of course, quite rapid as compared with cutting and stack-

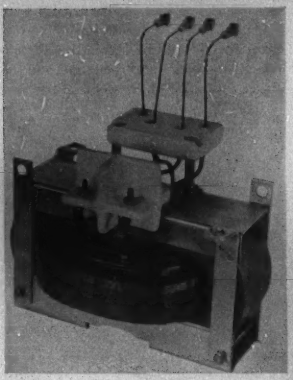

Figure 10. Core and coil unit with clamps and terminals

ing the hundreds of individual punchings which would be required to make equivalent cores of the old type. The space factor of the wound core is materially higher than with assembled punchings, reaching values of 95 per cent to 96 per cent.

The cores are annealed through a cycle which has been developed for this new material and are then delivered to the assembly room. It should be noted that the equipment necessary for putting the core into shape for assembling consists of a single core-winding machine as against an otherwise large investment in heavy high-speed punches and punching dies. The operation of gathering and stacking punchings for anneal is eliminated and several operations of grouping punchings by weight and number after anneal are eliminated.

Coils

The coils for these small transformers are of more or less normal design. They are of oval shape and short axial length. The inner and outer low-voltage coils are of shorter axial length than the high-voltage coils so that when assembled in a low-voltage-high-voltage-low-voltage group, a cross section of the group is of cruciform shape to conform to the circular window of the core. The internal insulation of the coils is similar to that which had been highly developed in past practice. The major insulation consists of mica pads between high and low-voltage windings taped on with varnished cloth and the entire group is taped and reinforced where it passes through the core. Where necessary for insulation or thermal requirements, ducts are placed between or within the coils. The corner ducts between the cruciform coil and the circular core provide satisfactory ventilation under the core and the remainder of the coil is fully exposed to the oil.

The arrangement and design of the coils is such as to give good transient voltage distribution and since the cores are applied under tension, the coils are firmly gripped and held in position against mechanical forces of short circuit. In these small units, no other mechanical bracing for the coils is essential.

Method of Assembly or Linkage of Cores With Coils

The two core units necessary for one transformer and its coil group are brought

Figure 11. Wound core and coil ready for assembly

Figure 12. First operation

Figure 13. Annealed core partially unwound

Figure 14. Annealed core completely unwound

Figure 15. Wound core in loose spiral around coil

Figure 16. Wound core tightly wound around coil

to a machine which has been developed for the operation of applying cores. The coil group is clamped between cushioned supports on this machine and one core unit is laid beside it over a short power-driven spindle (figure 11). The relative positions of the core and coil are properly adjusted and the welds which secure the outer end of the core strip broken. This outer end is then carried through the coil window in a large loop and temporarily secured on itself so as to form a circle embracing the coil leg (figure 12). A friction roller on the outside of the core and the internal spindle then rotates the core in such a fashion that its entire length is thrown out into a large cylinder embracing the coil leg (figures 13 and 14). The spindle within the core is removed and the core collapses into a loose spiral embracing the coil leg (figure 15). The temporary attachment on the outer turn is now broken and the turns of the loose spiral are drawn inward on the coil leg by power-driven friction rollers applied at its perimeter, with the result that the core is now linked with the coil leg in essentially the same condition as before the operation was began without having been overstressed during the operation (figure 16). The other core unit is similarly applied to the other leg of the coil group. The outer ends of the strips are welded to permanently secure the cores in shape, and the core and coil unit is ready for clamping, treating, and assembly in the tank. The operations described are rapid and somewhat less dependent on the skill which is necessary to obtain good joints and compact construction in a core made of cut punchings. The machines used at this point are an added investment since cores made of punchings are usually assembled by hand labor.

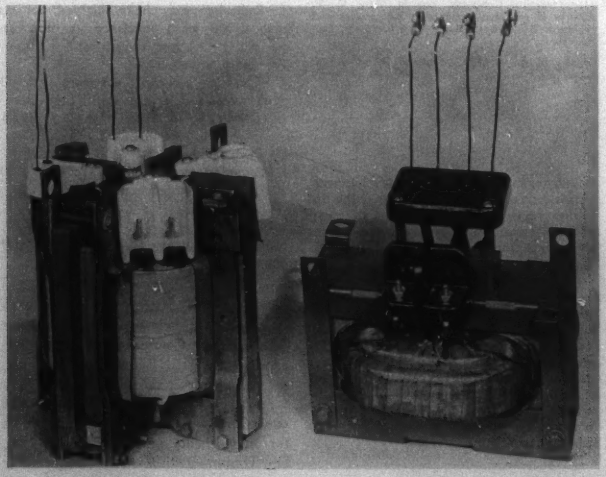

Figure 17. Transformers of distributed-core and wound-core construction

Clamps

Clamps are simple cradles of relatively light steel adapted to grip the cores securely and without distorting them. The structure of the cores is inherently solid and self-supporting.

Characteristics

In over-all characteristics, these transformers have been designed for characteristics which differ only slightly from previous values. In recognition of the importance of improving regulation, the copper loss of the wound-core transformers has been reduced and the core loss slightly increased. This revision of losses seems to be better suited to average operating conditions throughout the country than previous values. The exciting current is lower than with past transformers for reasons given earlier in this paper.

The wound-core distribution transformers, because of a marked reduction in the amount of copper and core iron used, and because of the lighter and simpler clamping structure required, are appreciably lighter in over-all weight than similarly rated units using the conventional core arrangements (figure 17).

Since the difficulty in serving small loads in areas of low density is largely

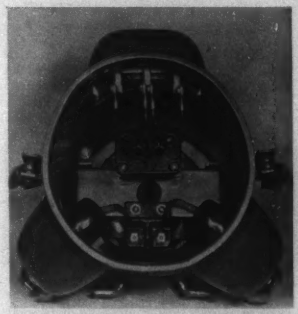

Figure 18. Wound-core unit assembled in tank

economic, the development of a material and a construction which permits reduction in the price of one important element in the cost of distribution would seem to constitute a major contribution to the broader use of electricity.

The writer wishes to acknowledge the assistance of others in the preparation of this paper, particularly of Mr. J. C. Granfield, the inventor of the wound-core construction, the method of assembly, and the machine, and Mr. M. Broverman who has closely followed the development.

Discussion

Philip Sporn (American Gas and Electric Service Corporation, New York, N. Y.): The distribution transformer, as is well known, plays a very important part in distribution economics. In some phases of distribution, for example in the problem of extension of rural service, it plays an almost predominating part. Here the transformer with its associated equipment represents from 35 per cent to 40 per cent of the average cost of a rural extension, taking for an average an extension in which from four to five transformer installations to the mile are made. Hence I think all electric utility and transmission and distribution engineers will welcome the development described by Mr. Treanor.

In reviewing the work that has been accomplished over the last decade in improving the characteristics and reducing the cost of the distribution transformer, it needs to be recalled that the present distribution-transformer design is basically a development and refinement of an idea that is

Radio Influence Characteristics of Electrical Apparatus

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Synopsis: Experience recorded in this paper with the method of measuring the radio influence factor of electrical apparatus recommended by the Joint Co-ordination Committee on Radio Reception of Edison Electric Institute, National Electrical Manufacturers Association, and Radio Manufacturers Association establishes its practicability and adequacy. This method fulfills the essential feature of all working standards in that the results are reproducible by quantitative measurements.

Various types of output meters for determining the radio influence factor of apparatus have been investigated. For practically all applications, the present type of output meter gives an indication which is sufficiently close to the audio output. This characteristic, besides the additional advantages it has in simplicity and relative inexpensiveness, well justifies its use.

Radio frequency influence factors vary in character, depending on the electrode insulation arrangement of the source, and also the dielectric medium.

Humidity and relative density of the air affect the radio influence factor and accordingly certain correction factors for the atmospheric conditions need be recognized.

The radio influence factor characteristics of insulation in air and oil, reported in the paper, establish that normally only apparatus in air need be considered for the effect of radio noise influence, as in coordinated apparatus design the strength of parts in oil will exceed those in air.

Experience has shown that quantitative data are essential for this type of study. Since adequate methods of measurements are available, the next step is the establishing of economical levels, which can only be obtained through the co-operation of all interested parties, by the collection of essential field data.

THE operating principles governing radiobroadcasting and reception are generally well-known. Good reception is possible from a radio receiver of suitable characteristics, provided adequate consideration is given to the receiving antenna and provided the field strength from the broadcasting station is sufficiently high. There are many factors detrimental to good radio reception. The signal may suffer distortion, undue weakening, or even complete obliteration at times from the effects in the transmitting medium and in the complex process of propagation of the signal.[1,2] Atmospheric electrical discharges and lightning superimpose their disturbances on the signal and may interfere partially or completely with reception over wide areas.[3] Another source of interference may be contributed from electric power systems and in fact from the very household electrical appliances, which, along with the radio receiver, are contributing to the conveniences and leisure in the modern home. The problems involved in securing good radio reception are therefore many and complex.

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1. For all numbered references, see list at end of paper.

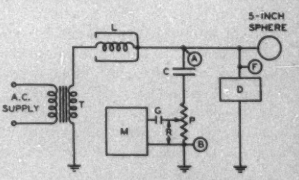

Figure 1. Recommended EEI-NEMA-RMA circuit for determination of radio-noise influence of high-voltage apparatus

T—Testing transformer
L—Radio-frequency choke, shielded, not less than 6,000 ohms reactance at broadcast frequencies
M—Radio noise meter
C—Coupling capacitor, not more than 60 ohms reactance at broadcast frequencies
G—Dummy antenna capacitor (21 micro-microfarads)
D—Device under test
P—Potentiometer or tapped resistor, 600 ohms resistance, nonreactive

This paper deals with the radio influence characteristics of electrical apparatus. As clearly defined by the Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA, improved broadcast reception is essentially a problem of co-ordinating the newer use of electricity and some of its older uses for light, heat, power, transportation, and communication. Accordingly after some years of experience and study this co-ordination body recommended suitable methods of measuring the radio influence factors of electrical apparatus.[4] This procedure naturally has unified effort, stimulated investigation of the problem, and it has made possible the progress which has already been achieved. The investiga-

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some 35 years old. Hence toward the last ten years the refinement and improvements that have been made have all been of a minor and detailed nature. In other words the vein in which distribution transformer designers were working was getting pretty thin. The development described by Mr. Treanor opens up a very definitely new vein. It shows very strikingly that only by using material and labor more effectively can costs be reduced in the long run. In opening up a new field for reducing both of those items Mr. Treanor and his associates have every reason to believe they have brought about a first class achievement.

It seems to me that the above is the outstanding phase of the development and that that is more important than some of the details as to how the characteristics of the particular steel that is utilized in the new design are obtained or how the ingenious arrangement for winding with so little labor the cores and placing them on the transformer has been worked out. The writer, and I feel certain many others who have been working in the field of improving distribution economics and reducing the cost of distribution of electric service, are looking forward to an intensive development of this vein and possibly to the opening up of new veins and the application of some of the economies already made possible on lower-sized transformers to larger distribution sizes where, if the need for reduction in costs is not as urgently pressing as it is in the field of smaller sizes, it is still nevertheless a major problem. There is no question that distribution costs can stand further reduction, but the distribution engineer needs material help from those who are spending all their energies in the field of designing and building the distribution equipment, the cost of which has a major influence on the whole problem of distribution economics.

E. D. Treanor: We feel with Mr. Sporn that the "vein" had been getting thin with conventional designs in spite of continued improvements in hot-rolled steel and that there is hope for a considerable extension on the new level. Initial progress may be slow but experience with the small units described inspires confidence that further effort along this line will be successful.

tion reported here fulfills further the aim and objectives of the Joint Co-ordination Committee in Radio Reception in establishing new data, findings, and principles that will be of assistance in the radio co-ordination problem.

Measurement and Testing Technique

The test circuit recommended by the joint co-ordination committee[4] for measuring the radio-noise influence factor of high-voltage apparatus is given diagrammatically in figure 1. The characteristics and adequacy of this method of measuring radio noise already have been dealt with to a considerable extent in the technical literature.[5] Its practicability has well been proved by the experience with the first installations and the design of recent installations. Two widely separated laboratories for measuring the radio-noise influence factor of high-voltage apparatus are shown, respectively, in figures 2*A* and 2*B*, and in figure 3. These installations comply essentially with the established recommendations. A brief description of the design characteristics of one installation will illustrate some of the more pertinent principles.

The physical parts of the installation which correspond to the circuit elements in figure 1 are indicated on the photographs. The possibility of appreciable or even measurable radio noise from the circuit proper was eliminated by the use of a 1⅛-inch diameter rod, five-inch diameter spheres at the ends, and adequacy of all apparatus parts. Special connecting links assembled from large-diameter rods and hemispheres are employed to connect the object under test to the circuit. A 50-kv testing transformer with regulator control supplies the required voltage over the entire range. The room was shielded with metal sheets spot-welded together and solidly connected to a grid system of large strap conductors and driven rods which comprise the ground. Power to the laboratory is supplied over a several-hundred-foot cable from a small transformer station which feeds as additional load part of the lamp circuit in the large plant nearby. By these measures in shielding the room and care in the choice of power supply, background and other interference from external sources were negligible, although immediately adjacent to the radio-noise laboratory is located a 3,000,000-volt impulse generator and also a high-current generator. The attainment of freedom from external noise sources is a feature which illustrates again the advantages and practicability of the recommended method.

The capacitance (C = 0.0021 microfarad) of the coupling capacitor and the effective inductance (L = 12 microhenries) of the drop lead are tuned to 1,000 kilocycles. The ratio of the radio-frequency voltages produced by the object under test on the measuring circuit and the recorded voltages appearing across the terminating resistance is essentially unity over the entire broadcast frequency range as is shown experimentally and by calculation in figure 4. This feature is a desirable one to attain.

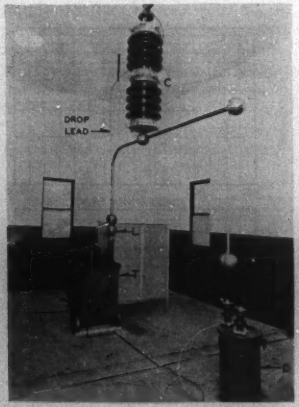

Figure 2A. View of Sharon laboratory

Figure 2B. View of Sharon laboratory

Calibration of the radio-noise meter is made by means of a high-frequency signal generator modulated 50 per cent at 400 cycles. The indication on the output meter from the unknown voltage is adjusted to half scale by a volume control on the noise meter. The signal generator is then switched on and its output varied until the same deflection is obtained on the output meter. All radio-noise measurements are therefore based on the signal generator and are microvolt root-mean-square values. The tests are usually made at 1,000 kilocycles which is midway in the broadcast frequency range.

Figure 3. View of East Pittsburgh laboratory

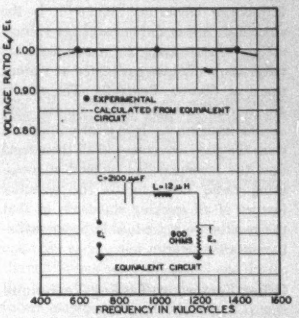

Figure 4. Characteristics of installation in figure 2

A typical set of tests, showing in figure 5, was made to correlate the measurements at the two laboratories. In test *A*, a rod to plate was employed; this electrode arrangement has served well as a "reference standard" in these and other comparative tests. Tests *B* and *C* were made on electrical equipment. The same samples of the equipment were tested first at one and then at the second laboratory. It should be noted that the laboratories are nearly a hundred miles apart. Though each conforms with the recommended method, they differ from each other in a number of details as

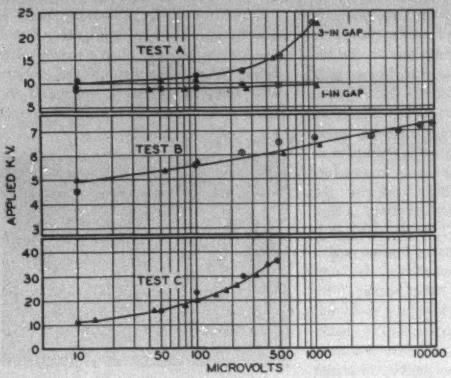

Figure 5. Correlation tests of two laboratories

shown by figures 2 and 3. The East Pittsburgh laboratory, figure 3, is the older installation and has a higher voltage rating. Again using the rod-to-plate arrangement, tests were repeated at various times at Sharon, figure 2. The results are plotted in figure 6 and similar data appear in figure 9. It is clearly apparent from the good agreement in all these tests that the recommended method of measuring radio noise fulfills the essential feature of all working standards in that the results are reproducible by quantitative measurement.

Other Factors in Testing Technique

Measurements were made on a pin-type insulator and on a rod-to-plate gap at various frequencies over the broadcast frequencies. The results are given in figure 7. These and similar tests indicate that the radio-noise influence factors decrease with increase in frequency. The experience up to the present time in testing high-voltage apparatus shows that a relatively uniform decrease in radio-noise influence factors is obtained over the entire broadcast range with no tendency in peaking of radio noise at one frequency. For this reason it appears that the practice in testing at some frequency midway in the broadcast band, such as 1,000 kilocycles, is justified.

The character of radio noise may differ considerably, depending on its generating source. Thus an important feature of the curves for the air-insulated (dry type) apparatus in figure 5 is the uniform continuity in the microvolt rise with increase in applied voltage. Physically the phenomena in these cases is one of uniformly increased radio interference factor with voltage. That the radio interference factor is sustained and uniform was evidenced also from the steady indications of the output meter. Distinctly different from this was the radio noise measured from a sphere to plate. As shown in figure 8, corona and spark-over for this electrode gap occur simultaneously up to about 3.5 sphere-diameter spacing. At the wider spacings corona appears before spark-over voltage is reached. From the visual and aural observations the corona is brusque, in the nature of streamer formation. In fact, the microvolt curves in figure 8 confirm this initial relatively intense discharge, as the lowest measurement that could be recorded is approximately 500 microvolts. The intermittent streamer discharges account also for the unsteady behavior of the output meter in these tests. A similar performance was recorded for the rod to plate above 25 kv where a discontinuity in the curve (figure 6) appears. In short, the two distinct types of corona effects referred to, well illustrate the different character of radio noises that may be encountered.

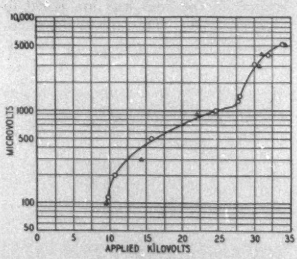

Figure 6. Comparative tests at one laboratory

Rod-to-plate gap, three-inch spacing

Other factors that need be taken into account in radio-frequency testing are the density and humidity of the air. It is recognized that breakdown and corona voltage both depend upon the relative air density and the absolute humidity. In general, the amount of correction for variation of the air density is small. Fundamentally, in radio-interference work this correction would appear to be proportional to the air density, the same as applied to voltage breakdown. Due to the fact that the effect of absolute humidity in high-voltage testing is relatively greater than the relative air density, it appeared desirable to determine its effect on radio-frequency testing.

Tests were made at one of the laboratories where by virtue of the enclosed room the absolute humidity could readily be controlled. First the tests were made at a low humidity. A certain amount of steam was then injected into the room and the air kept well stirred up until the higher humidity was uniformly attained in the room. The tests were repeated. Thus the testing at the two humidities and with identically the same test setup was completed in an hour or less. Results for the rod to plate are given in figure 9. These data have been confirmed by other tests. This investigation establishes that for the rod to plate and for similar electrode arrangements the voltage corresponding to a given radio noise value increases with the absolute humidity 1.5 to 3.0 per cent for each grain per cubic foot. On the average the increase is 2.5 per cent over the entire range in figure 9. This variation in humidity correction factor for radio noise is substantially the

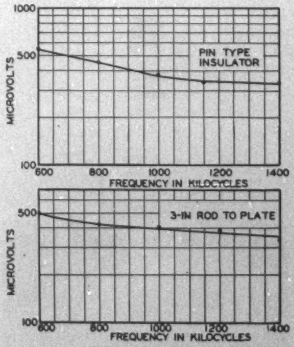

Figure 7. Comparison of tests over the broadcast range

Relative air density = 0.98
Absolute humidity = 4.4 grain per cubic foot

same as that applied to 60-cycle flashover of rod gaps and suspension insulators.[6] Below the very low values of 50 to 100 microvolts the microvolt correction for humidity becomes insignificantly small.

Comparison of Noise Meters

The Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA have formulated specifications for a radio noise meter. These specifications were formulated at the time when tuned-radio-frequency receivers were the most commonly used but since that time the designs of the radio receivers have changed considerably. The selectivity curves of radio receivers are a major characteristic which affects the response of radio receivers to extraneous noises. While the tendency in the past has been toward greater selectivity, the demand for higher fidelity in recent years has required the manufacturing of less selective receivers. Although the specifications for the radio-noise meter were formulated in 1931, no changes in these specifications have been found necessary.

Table I. Selectivity of Three Receivers

Receiver	Band Widths (Kilocycles) Versus Signal Ratio					
	600 Kc		1,000 Kc		1,400 Kc	
	10/1	100/1	10/1	100/1	10/1	100/1
A	12	24	18	37	31	64
B	10	17	9	15	9	19
C	12	22	21	40	27	59

In order to determine the relative response of three different radio instruments that are being used in the laboratories for measuring radio-frequency influence factors, radio-frequency voltages of different character were measured with the three instruments. Two of these instruments are of the tuned-radio-frequency type; the third is a superheterodyne receiver.

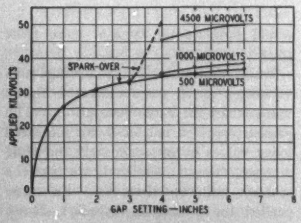

Figure 8. Sphere-to-plate tests illustrating character of radio noise

Two-centimeter sphere to plate

The curves in figure 10 show the results of these three receivers when measuring the radio influence factor from a rod to plate gap separated three inches. This type of noise has produced the greatest deviation between receivers. Figure 11 shows the results when measuring the radio-influence factor from a pin-type insulator. It should be noted that the superheterodyne receiver *B* indicates a value of noise which on the average falls between the two tuned-radio-frequency noise meters.

The selectivity curves of all receivers are shown by table I and it is interesting to note that although the superheterodyne receiver *B* is highly selective at 1,000 kilocycles, the results obtained by this instrument are relatively close to the tuned-radio-frequency instruments. The maximum deviation that has been noted in the values indicated by the three instruments has been slightly over two to one. These instruments do not always maintain the same relative position as shown in figures 10 and 11. In some cases, receiver *B* will measure less than receivers *A* and *C* but always within the deviation limits given above.

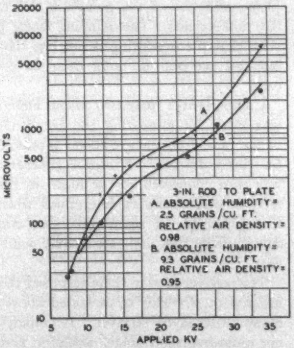
MICROVOLTS
APPLIED KV
3-IN. ROD TO PLATE
A. ABSOLUTE HUMIDITY = 2.5 GRAINS/CU. FT. RELATIVE AIR DENSITY = 0.98
B. ABSOLUTE HUMIDITY = 9.3 GRAINS/CU. FT. RELATIVE AIR DENSITY = 0.95

Figure 9. Effect of humidity

Instruments *A* and *C* correspond to the specifications formulated by the Joint Co-ordination Committee on Radio Reception. The output of instrument *A* is highly distorted for values of interference above 1,000 microvolts. This distortion does not exist in either the superheterodyne receiver *B* or instrument *C* up to values in the order of 20,000 to 30,000 microvolts. Repeated tests have indicated that the higher values measured by instrument *A* are in error. A potentiometer is now being used with instrument *A* so that all voltage measurements are made below 1,000 microvolts. With this arrangement consistent results are obtained between the three instruments.

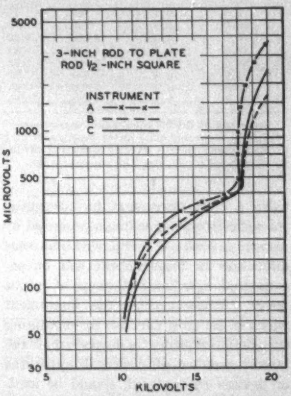

Fig. 10. Comparison of radio-frequency voltages measured by three instruments (tests on rod gap)

Relative air density = 0.99
Absolute humidity = 3.5 grains per cubic foot

Instruments *A* and *C* are battery-operated radio-noise meters. Because of the continuous service required and due to the fact that the superheterodyne receiver incorporated a loudspeaker, it was used in obtaining a portion of the data presented in this paper. It is not advocated however to substitute any radio receiver for the recommended radio noise meter unless facilities are available to determine the relative merits.

Output Meter

The joint co-ordination committee specifies that the output meter for the radio-noise meter should be a critically damped instrument having an undamped period of one-half second. The present noise meters have a Rectox-type output instrument which gives an average value of the radio interference voltage. There has been and probably will be in the future more or less criticism of the output instrument specified by the Joint Co-ordination Committee on Radio Reception. The problem of selecting such an instrument is similar to that which has been encountered by committees in standardizing on a sound level meter. Some feel that the meter should be faster, others feel that the output meter should be over-damped. Still, others advocate

Table II. Radio-Frequency Voltage and Noise Measurements

Voltage Applied Rod Gap (Kilovolts)	Output Meter** Milli-amperes	Micro-volts	Noise Level (Decibels) (40)*	(80)*	Noise Intensity (Micromicro-watts)	Noise Loudness
16.6	0.1	680	75	75	3,200	11,750
20.0	0.2	940	80.5	80	11,250	17,000
20.7	0.3	1,150	82	82	16,000	19,500
22.0	0.4	1,300	84.5	84.5	28,300	24,000
23.5	0.5	1,400	85.5	85.5	36,000	25,000
25.8	0.6	1,550	87	87	50,000	28,500
27.0	0.7	1,700	87.5	87.5	56,000	30,000
27.3	0.8	1,820	90	90	100,000	37,000

* Forty and 80 decibel equal-loudness contours.
** Volume control of noise meter (instrument *B*) at 45 on dial. Microphone one foot directly in front of the loudspeaker.

using a crest instrument for measuring the radio-frequency voltages produced by various devices. It is apparent that some difficulties in measurement will be encountered regardless of the type of output meter. Consequently, the instrument which is the most effective for measuring the radio-frequency voltages from the largest number of electrical apparatus or devices encountered, should be used.

It was realized that the crest voltage produced by the majority of electrical devices or apparatus would not compare favorably with the loudspeaker response. Consequently, it was felt that an averaging tube voltmeter, such as is being used for monitoring broadcasting stations (figure 12) might be an adequate compromise between measurements of peak values of noise by the grid bias and measurements of average values with a highly damped and slower instrument as recommended by the joint co-ordination committee. An investigation was conducted in the laboratory to determine the performance of this average tube voltmeter (figure 12) as compared to the Rectox-type output meter. This average tube voltmeter circuit is such that peaks of duration between 40 and 90 milliseconds are indicated to 90 per cent of full value and the discharge rate adjusted so that the pointer returns from full reading to 10 per cent of zero within 600 milliseconds. The speed of the indicating meter is such that the time for one complete oscillation of the pointer is 290 to 350 milliseconds. The damping factor is such that the overswing is not less than one-half per cent or more than six per cent.

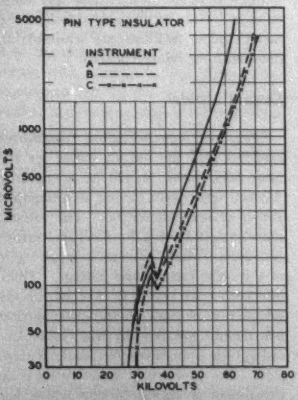

Figure 11. Comparison of radio-frequency voltages measured by three instruments (tests on insulator)

Relative air density = 1.0
Absolute humidity = 1 grain per cubic foot

Comparison of these two output meters was made by measuring the amplitude of the radio-frequency voltages produced by three devices. A signal generator was then connected to the input of the receiver and observers determined when the output of the signal generator and device under test indicated equal loudness.

The receiver used in these tests was the instrument *B*. This is, as stated above, a superheterodyne receiver. It employs one radio-frequency stage, oscillator, first detector, two intermediate amplifiers, second detector, and push-pull audio amplifier. A circuit analysis of it appears in *Radio*, November 1930. This receiver was equipped with a loud speaker. A Rectox output meter and the averaging tube voltmeter were connected in parallel and condenser coupled to the plates of the push-pull amplifier.

In making the measurements, the sensitivity of the receiver was adjusted so that the output of the noise was sufficient to give half scale deflection on the Rectox meter. The input potentiometer on the crest instrument (average tube voltmeter) was then adjusted so that maximum deflections could be read on the scale. A more exact determination of the pointer deflections was obtained by holding the edge of a card in front of the dial and adjusting it so that the needle was just visible for maximum variation. The adjustment of the input potentiometer was not changed during the time of test with any one observer. A signal generator with a 400-cycle audio component, and 50 per cent modulated output, was substituted for the noise source to determine the value of these two noise levels in microvolts.

The observer then compared by ear the relative volume obtained from the loud speaker when the noise source was connected to the receiver and when the signal generator output was substituted for the noise. The sensitivity of the receiver was held constant and the signal generator output adjusted until the two seemed to be of equal loudness.

The curves in figure 13 show the results of tests made with a 110-volt a-c universal-type motor, 33-kv pin-type insulator, and spark gap, respectively, as the source of the noise. The spark gap was used to produce a peak discharge which would simulate the type of noise from ignition systems.

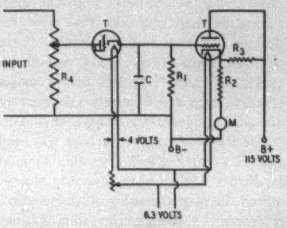

Figure 12. Circuit diagram of average tube voltmeter

R_1—40 megohms
R_2—68,000 ohms
R_3—680,000 ohms
R_4—500,000 ohms
C—0.007 microfarad
M—Rectifier-type meter
T—Tube type 76

It should be noted that the average tube voltmeter in all cases indicated higher values than the audio comparison. The present specified output meter indicated lower values by approximately the same amount. Present data indicate that the sensory build-up time, i.e., the time needed for a suddenly applied steady wave to build up to a steady loudness, is in the order of 0.2 to 0.25 seconds.[7] The average tube voltmeter will measure peaks of much shorter durations than the ear while the present output meter will only measure peaks of longer durations.

For practically all applications it appears that the present type of output meter gives an indication which is sufficiently close to the audio output of a

radio receiver. This characteristic well justifies its use. It has the additional advantage of being simple and inexpensive which is highly desirable for industrial laboratory and field work.

Correlation Between Radio-Noise Measurement and Acoustical Loudness

The desirable radio noise measuring instrument is one that would indicate values which simulate the ear response. The American Standards Association has published tentative standards for acoustical noise measurement[8] and has

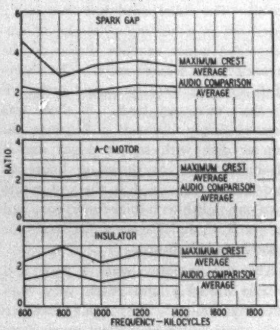

Figure 13. Comparison of audio, average, and crest values

formulated the requirements of sound level meters for measurement of noise and other sounds.[9] This instrument attempts to approach the human ear by weighing the various audio-frequency components with respect to the standard 1,000-cycle reference loudness level.

It is interesting to note that the radio noise meter and the sound level meter primarily attempt to determine or weigh the effect of two different types of complex waves on the ear. One is used to measure the modulated high-frequency voltage while the other measures sound picked up by a microphone.

Tests were conducted to determine if any relationship existed between measuring the output of the radio set with Rectox-type output meter (instrument *B* in figures 10 and 11) and with a sound level meter which complies with the ASA standards.[10] The modulated radio-frequency voltages were produced by a rod-to-plate gap and measured by the standard radio noise method. In measuring the audio output of the radio set, the microphone of the sound level meter was placed at a distance of one foot directly in front of the loudspeaker. The scale of the output meter was zero to one. The volume control was adjusted for 0.1 on the output meter and the radio-frequency voltage and the sound level meter readings taken. The voltage on the rod gap was increased and for every 0.1 increase in deflection on the output meter, the modulated radio-frequency voltage and the sound level noise meter readings were noted.

Table II shows the results obtained with one sensitivity setting of the radio set. The radio-frequency voltages increased from 680 to 1,820 microvolts. The noise level increased from 75 to 90 decibels and the auditory sensation or loudness from 11,750 to 37,000 units. It should be noted that the microvolts increased 2.68 times and the auditory sensation 3.15.

Figure 14 shows three curves, each taken at a definite sensitivity and covering a given range of microvolts. In these three measurements the microvolts increased, respectively, 2.0, 7.0, and 4.0 times and the corresponding noise loudness increased 1.5, 5.5, and 5.2. These tests were made with the radio set at 1,000 kilocycles. Similar tests as for curve *C* but at 1,400 kilocycles gave a microvolt increase of 5.6 times against a loudness increase of 4.4 and at 600 kilocycles the microvolts increased 5.1 and the loudness 5.2.

Similar relationships in the relative increase between microvolts and loudness as shown in figure 14 were obtained with the microphone at greater distances from the loudspeaker. For instance, in one test similar to curve *C* but with the microphone placed at two feet directly in front of the loudspeaker, the microvolts increased 6.3 times while the loudness increased 6.0 times.

All these tests were made in one of the two laboratories where inherently the background noise level can readily be reduced to 50 decibels and even less so that it practically had no influence or required no compensation on the tests proper. An attempt was made to analyze the frequency components of the loudspeaker noise. It was found that the frequencies contained in this type of radio noise were too numerous and complex to permit frequency analysis.

From these tests the ratio of the increase in microvolts to the increase in auditory sensation did not vary more than 0.77 to 1.34. In a number of cases and on the average the ratio was close to one. If we assume that the response of the sound level meter simulates the human ear response, we can accordingly assume that

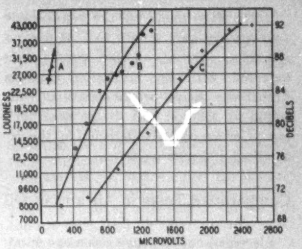

Figure 14. Correlation between radio noise measurements and acoustical loudness

Noise meter at 1,000 kilocycles
Volume dial setting *A*, *B*, *C*
Microphone one foot in front of loud-speaker
Radio-frequency voltage from three-inch rod to plate

our present output meter likewise corresponds in effect somewhat to the response of the human ear.

Comparative Measurements of Corona Starting Voltage

Various means have been employed in determining the starting voltage of corona of high-voltage equipment. Recently tests were conducted to determine the effectiveness of detecting corona starting voltage by the use of a cathode ray oscilloscope, ear, eye, and the standard method of measuring radio noise.

Difficulty was encountered in attempting to use the cathode-ray oscilloscope and after considerable experimenting, an untuned radio-frequency choke coil was connected in series with the ground lead of the apparatus. A parallel resonant circuit tuned to 1,185 kilocycles was connected across this choke through a blocking condenser. The oscilloscope was then connected across this resonant circuit. By this means, the 60 cycle and low frequency harmonics were filtered out.

The tabulation below shows the threshold of corona by different methods from three pieces of apparatus. The standard method of measuring radio noise detected the lowest starting voltages.

In totally inclosed apparatus, the standard method of measuring radio noise detects corona starting voltage very much below the audible or visual methods.

Sample	Kilovolts			
	Audible	Oscilloscope	Visual	Radio
High-voltage switch	26.0	28.2	26.0	20.0
Current transformer	11.0	12.0	12.0	6.2
Circuit breaker	6.1	7.7	13.0	4.85

Tests were made on the rod-to-plate (one-quarter-inch square rod) at various spacings. Initial audible corona was detected with an insulation tube of funnel-like shape which conveyed the sound at the rod end to the observer's ear. Corona could be detected by the ear at about 100 microvolts.

Comparative Tests in Air and in Oil

Electrical apparatus assumes many forms, depending on the application and on the design. It is apparent that a complete survey of the radio-noise influence of all apparatus would require an extensive program, although a good deal of work already has been done in this direction. However, an appraisal of this problem is simplified when it is recognized that most apparatus at the present operates either in air or in oil. The corona characteristics of these two dielectrics either alone or in combination with the dielectric bodies of the apparatus proper, such as porcelain, fullerboard, and so on, are important factors in a survey of the radio noise influence of electrical apparatus. Certain principles will become apparent from a consideration of typical tests which have been made in air and in oil.

Tests in air are shown in figure 15. These characteristic curves bear out in the first place the influence of the shape of the electrode. The radio noise measurements and therefore corona appear at a lower voltage when the electrode is a plain rod and it can be seen also that the characteristic curve is essentially the same whether this is a one-quarter-inch square rod or a one-eighth-by-one-inch rectangular strap. The curves show that for the same microvolt level twice the voltage may be applied to the sharp-cornered disk as compared to the voltage on the rod. A rounded electrode such as a sphere of sufficiently large diameter presents certain advantages in reducing corona formation, provided the surface of the electrode is kept clean. In practice apparatus may be exposed to dirt, moisture, rain, and so on, with the result that large smooth surfaces are in such case more detrimentally affected than would be the sharper-edged electrodes.

A point of interest in the characteristic curves for air (figure 15) is that considerably higher microvolt values are reached by the short gaps. Thus with the one-half-inch gap spacing, for either the rod or disk-type electrode, very high radio-frequency voltages can be generated whereas for the correspondingly larger gaps sparkover occurs before these high values can be reached.

In electrical apparatus the body of a solid dielectric or a combination of dielectrics appears between the line and ground electrodes assuming one form or another which depends on the design and the application of the apparatus. If the presence of the dielectric body increases or decreases the stress on the air as compared to the stress between the electrodes in air alone, then the microvolt-voltage characteristic curves will accordingly be modified, respectively, upward or downward. Thus the presence of the porcelain body in the case of the line insulator may further raise the microvolt-voltage curve in comparison to that of the tie wire and pin electrode in air alone. By proper design and grading of the body part, the stress on the air may be reduced. In the case of a condenser-type bushing the inherent grading of the stress in the dielectric body and over its surface contributes also in reducing the stress in the adjacent surrounding air. In this case the stress on the air at the line terminal even for sharp electrode parts is much less than it would be anticipated from the stress which appears between the terminal electrodes in air alone. It is apparent then that the radio-frequency voltage from electrical apparatus in air depends essentially on the relative stress imposed on the air. Characteristic curves of the air alone as shown in figure 15 are nevertheless of fundamental guidance in appraising the general problem.

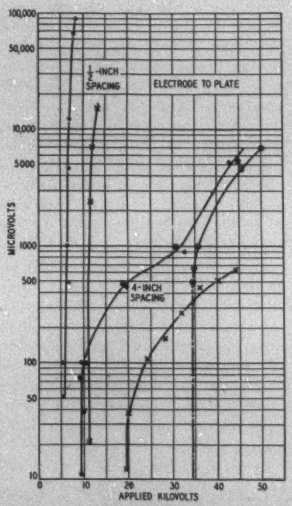

Figure 15. Radio-noise characteristics of air for various electrode arrangements

Type of electrode:
- ● One-quarter-inch square rod
- ⊡ One-eighth by one-inch rectangular strap
- × Nine-inch diameter, one-inch thick disk
- ⊙ 0.8-inch diameter sphere at end of one-half-inch diameter rod

The rod-to-plate gap was tested in oil at spacings from a fraction of an inch to an inch. The voltage was raised until breakdown of the oil gap occurred so that up to 45 kv was applied for the larger gap tested. No radio-frequency voltage could be detected up to breakdown of the gap.

Tests were made on fullerboard sheets in oil. The fullerboard was thoroughly dried out in a heating oven and oil impregnated under vacuum similar to the treatment for transformers. The sheets of fullerboard were immersed under oil in their own test tank. A sheet was pressed firmly between a $2^1/_2$-inch diameter disk with square edges and a grounded plate, as shown in figure 16 and tested. Curve *A* is the test result for a one-eighth-inch thick fullerboard and curves *B*, *C*, and *D* give similar tests for 0.056-inch fullerboard.

The characteristic curves *A*, *B*, *C*, and *D* rise abruptly and reach very high microvolt values. They clearly indicate that corona in oil is in effect much more intense than in air. In similar tests that had previously been made on the strength of insulation[11] the corona at the edge of the disk was detected visually at about 25 kv and 36 kv for the 0.056-inch and one-eighth inch fullerboard sheets, respectively. It appears to the writers that the radio noise method is also an effective means to study and measure corona. When the phenomena is partly or entirely concealed, such as is in these tests, it has been found a superior method to any of the others available. To illustrate this point further, a one-eighth inch fullerboard sheet that had not been dried or treated was tested. The results are plotted in curve *E* which by comparison to curve *A* show the benefits which accrue from drying and treating the fullerboard.

In practical design even for the lower classes of distribution apparatus, clearances in oil normally exceed the amount indicated in figure 16. The mechanical requirements alone generally require larger clearances. Besides the conducting parts normally are insulated thus securing relatively better performance than indicated. Considering the fact that the corresponding air clearances would be in the order indicated in figure 15, it is clearly apparent that the radio noise in-

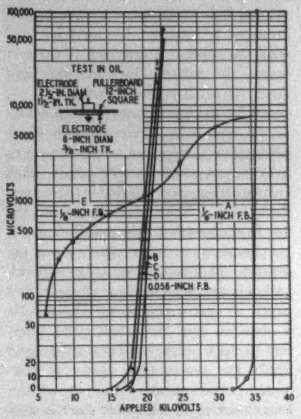

Figure 16. Radio-noise measurements of insulation in oil

fluence of electrical apparatus principally concerns the apparatus or the part of the apparatus in the air. Similar consideration of and experience with voltage apparatus of higher voltage classes likewise establish that normally only the apparatus in air need be tested for the effect of radio noise influence as the strength of the apparatus or corresponding part in oil well exceed in good design those in air.

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Discussion

C. W. Frick (General Electric Company, Schenectady, N. Y.): During the past six or seven years considerable experience has been gained with methods of determining radio influence characteristics of apparatus at several different laboratories and to some extent in field investigations. The present paper is a valuable contribution to this work. As the paper points out, the Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA has recommended circuits for the determination of interference influence of high-voltage and low-voltage apparatus. The quantity which is measured is called noise voltage in the committee report and is expressed in modulated microvolts, but in the paper it is called the radio influence factor. The name used in the paper has considerable merit because the quantity in question serves as an index of influence on radio reception. In this respect it is analogous to the telephone influence factor (TIF) which is a useful index of the influence of power-system wave shape on wire communication systems. On the other hand, the present name, noise voltage, has some advantage because it suggests the units in which the quantity is measured while a factor is generally thought of as a ratio, for instance power factor, form factor, space factor, and similar terms. The joint committee has not as yet adopted the name radio influence factor, and those wishing to use the term should explain its meaning as the authors have done.

The paper presents an interesting study of the effect of different types of output indicator. The present output meter is a microammeter which indicates an average of the rectified output of the radio receiver element of the noise meter. It is a critically damped instrument having an undamped period of 0.5 second as specified by the joint committee. Some engineers have suggested that an instrument which responds to noise peaks might give a better indication of the effects on radio reception. The paper compares the present output meter with one consisting of a tube voltmeter operated on a capacitance-resistance network characterized by rapid charge and slow discharge so that it tends to average the noise peaks. The authors call this an averaging tube voltmeter. Figure 13 of the paper shows that this averaging tube voltmeter gives higher readings than the present output meter for common types of noise, such as motor noise; that is, it requires a higher value of the calibrating voltage modulated 50 per cent to match the noise indication on that instrument than it does when the present output meter is used. This result would be expected because noises appear to consist of a rapid series of impulses. The curves also show that readings with the two instruments are different in ratios for different types of noise.

When the joint committee's specifications were prepared, it was realized that radio noise is quite complex and its effects on reception involve many factors including those associated with loud-speakers and with the ear. It was felt that the thing to do was to set up the best instrument that could be obtained according to the state of the art then, and to make improvements later as found necessary. Therefore they specify certain electrical characteristics for the receiver element and a certain period and damping for the output meter, based on the information then available. The paper includes an additional check on the present output meter by an ear comparison method where the noise is compared with the calibrating tone as heard in a loudspeaker. The curves of figure 13 for this audio comparison show better correlation with the present method than obtained by a similar test with the averaging tube voltmeter method. The present type of radio noise meter has been in the field for several years and has made it possible to collect useful data on common types of noise from different observers. For this purpose it seems to be better than anything else that has been suggested.

P. H. McAuley (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The authors have demonstrated the practical nature of the circuit recommended by the joint co-ordination committee. The radio influence factor of high-voltage apparatus can be checked in different laboratories at different times with different types of meter with good agreement. In addition to the East Pittsburgh laboratory described in the paper, which has been in operation since 1930, radio interference tests have been made at the Trafford laboratory from time to time. One of the 500-kv transformers is used, but the capacitor stack at present limits the voltage to about 200 kv. However, it is possible to test the highest voltage apparatus above its operating voltage to ground. At voltages above 150 kv, corona on leads and connections becomes somewhat of a problem. So far we have been able to use two-inch-diameter aluminum tubing with carefully made joints. Six-inch spheres are used at the ends. In general, a radio influence test, on 230 kv apparatus for instance, requires a careful arrangement of the complete high-voltage circuit.

For many years the laboratories have been able to make reliable tests. The crying need for years has been the establishment of levels of permissible noise for different classes of equipment. We are able to determine the radio influence characteristic curve of a piece of apparatus but we are unable to say whether it is satisfactory at its rated voltage. The establishment of levels is essentially an operating problem, because they should be based on experience with equipment now in service. It is hoped that it will soon be possible to correlate field and laboratory testing to the extent that permissible levels satisfactory to both manufacturer and user can be set.

A Position Regulator for Paper Slitters

By F. H. GULLIKSEN
MEMBER AIEE

PAPER slitters are used to trim the edges of paper webs so that a paper roll with even sides can be wound from an unevenly wound roll. When the paper has printed designs on it, the slitting must be done at a definite distance from the printed design. The slitter knives are

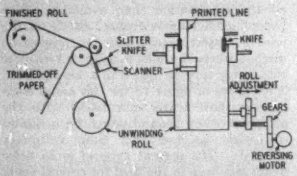

Figure 1. Schematic arrangement of paper slitter

stationary as shown in figure 1. In order to slit the paper at the same position relative to the design when the position of the paper relative to the shaft of the unwinding roll is varying, it becomes necessary to adjust the position of the unwinding roll transversely.

To do this, a line is printed on the paper as part of the printed design and a phototube is arranged to scan this line. Through suitable electronic equipment and a reversing motor, the position of the unwinding roll is adjusted to keep the paper in the same position in relation to the slitter knives.

It has been customary to use a scanner with two phototubes which would scan the line printed on the paper as shown in figure 2. The phototubes were connected in a bridge circuit and the output of the bridge circuit was used to control the electronic regulator and the reversing motor.

The paper industry requires that the line printed on the paper should not be wider than one-eighth inch, which necessitates focusing the two light beams one-eighth inch apart, and obviously, the range of control with the scheme shown in figure 2 will be only one-eighth inch. If the paper, therefore, should move outside the one-eighth inch range, the regulator would lose control. It is also evident that any change in phototube or lamp characteristics would change the regulating position.

The purpose of this paper is to describe a new slitter regulator which employs only one phototube, and which widens the range of control to one inch regardless of the width of the printed line.

The Single Phototube Scanner

The new single phototube scanner shown in figure 3 consists of an 1,800-rpm synchronous motor with four lenses mounted on its shaft. A lamp is mounted as shown in figure 4 so that the lenses focus four light beams on the paper and the printed indicating line. A phototube is arranged to intercept the light reflected from the paper. A top view of the four lenses, the printed line, and the light beams L_1 to L_4, is shown in figure 5. In figure 5*A* the line is located in the center of the light-beam circle while in figure 5*B* the line is displaced to the left. The light beams rotate synchronously, each beam making one revolution in two cycles. Each time a light beam intercepts the line in the position indicated in figure 4, the illumination on the phototube is decreased. This change in phototube illumination is amplified as shown later in this paper, so that a peaked voltage impulse is obtained once every half cycle, referring to the frequency of the a-c source to which the synchronous motor is connected. The angular position of the lenses relative to the motor shaft is such that when the line is in position *A* the impulse voltage occurs at 90 degrees phase angle, whereas with the line in position 5*B* the impulse voltage location is advanced as shown in figure 6.

For every position of the line on either side of the center position, an impulse is obtained, and there is a definite relationship between the angular location of the impulse voltage relative to the a-c supply voltage, and the space location of the line. This relationship is used to indicate the position of the paper.

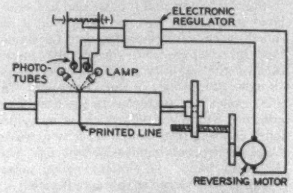

Figure 2. Slitter regulator employing two phototubes

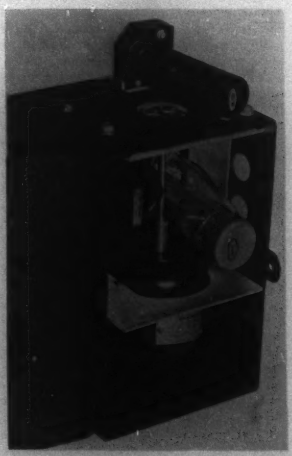

Figure 3. New scanner with one single phototube

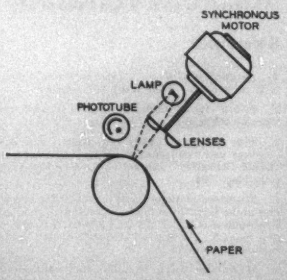

Figure 4. Schematic arrangement of single phototube scanner

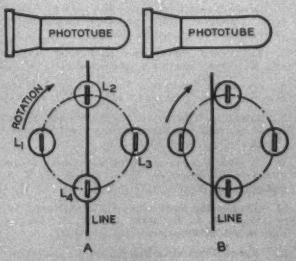

Figure 5. Development of light beams

Paper number 38-64, recommended by the AIEE joint subcommittee on electronics and presented at the AIEE summer convention, Washington, D. C., June 20–24, 1938. Manuscript submitted March 25, 1938; made available for preprinting May 19, 1938.

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The Amplifier

A conventional amplifier with capacitor coupling in the grid circuit and transformer coupling in the anode circuit is used as shown in figure 9. The amplifier tube is normally biased to give a high anode current. When one light beam intercepts the line, and the illumination on the phototube is decreased, the grid of the amplifier tube is made highly negative and the anode current is decreased, thus giving an amplified impulse on the secondary side of the anode circuit transformer. This impulse is used to control the selective indicating circuit.

The Selective Indicating Circuit

The purpose of the indicating circuit is to detect the phase-angle location of the voltage impulse obtained from the amplifier. To make the circuit independent of variations in supply voltage and tube characteristics the circuit is arranged to respond only to phase angle.

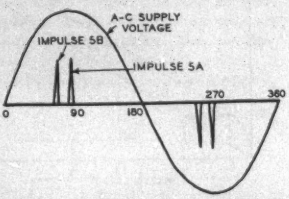

Figure 6. Location of the impulse voltage for positions 5A and 5B

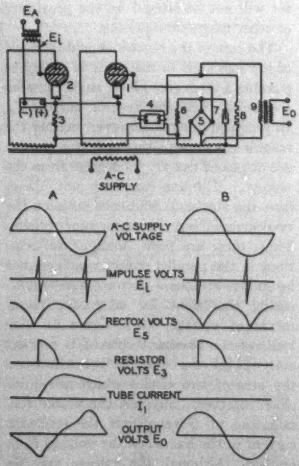

Figure 7. The selective indicating circuit

As shown in figure 7 two thyratron tubes 1 and 2 are used. The grid-control voltage for tube 2 is the amplified impulse voltage from the phototube, connected in series with a negative d-c bias voltage, and tube 2, therefore, is initiated at a point on the a-c voltage wave dependent upon the location of the impulse voltage E_t, which, as previously outlined, is a function of the space location of the line. When tube 2 becomes ionized, rectified

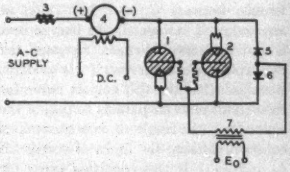

Figure 8. The motor-control circuit

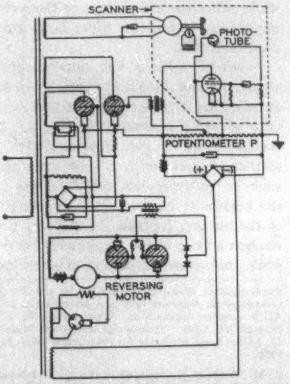

Figure 9. Schematic diagram for position regulator

a-c voltage appears across resistor 3, and persists during the remainder of the half cycle. The voltage across resistor 3 is connected in negative sense in the grid circuit of tube 1, so that tube 1 cannot become ionized if current is already established through resistor 3. Tube 1 has a permanent negative grid bias obtained from Rectox rectifier 5, which is supplied with a-c voltage from the 90 degrees phase-shift circuit consisting of resistor 6 and capacitor 7.

Because of the interlock action of resistor 3, tube 1 does not conduct current if the impulse voltage E_t occurs ahead of the 90 degrees position as shown in the curves in figure 7*B*. If the impulse voltage occurs later than the 90 degrees position current I_1 flows as indicated in figure 7*A*.

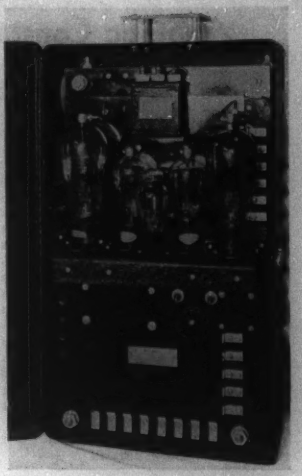

Figure 10. A front view of the regulator cabinet

A saturable transformer 4 is connected in series with tube 1, and the secondary winding of this transformer is connected in a bridge circuit with resistor 8 so that the output voltage E_0 of transformer 9 is reversed when the primary winding of transformer 4 is energized. If, therefore, the line on the paper is moved from one side of the central position to the other, a 180 degrees reversal of voltage E_0 results. This condition is used to obtain reversal of the armature voltage for the roll-adjusting motor.

The Motor-Control Circuit

As shown in figure 8 two thyratron tubes 1 and 2 are used to supply reversiable rectified a-c voltage to the armature of the roll-adjusting motor. When tube 1 is conducting current the armature voltage polarity is as shown in figure 8. Reversal of armature polarity results when tube 2 is conducting. The current through tubes 1 and 2 is controlled by means of voltage E_0. Reversal of this voltage, in the manner previously described, reverses the grid polarity of the tubes so that one tube becomes ionized and current stops flowing in the other tube. Rectox rectifiers 5 and 6 are used to refer the grid voltage to the cathode of that tube whose anode at that instant is positive relative to the cathode.

Reactor 3 is used to limit the tube

A Static Constant-Current Circuit

By C. M. SUMMERS
ASSOCIATE AIEE

Synopsis: Static constant-current circuits have been constructed by connecting an iron-core reactor, with predetermined characteristics, in parallel with a capacitor of a specified size such that the resultant input current is independent of line voltage. This parallel circuit is connected in series with the element through which the current is to be regulated. The current will remain essentially constant for large variations in line voltage; large variations in load impedance; or a variation in both quantities simultaneously as long as the variation in voltage across the parallel circuit does not exceed certain limits. This type of circuit is useful for applications where a constant heating independent of line voltage is desired; for series lighting circuits; and vacuum-tube filament circuits.

AN IRON-CORE reactor and a capacitor, connected in parallel, are the essential elements of a static, a-c, constant-current circuit, providing these elements are operated within certain specified conditions. First, there must be a predetermined relation between the reactor and capacitor; second, the variation in voltage across this parallel circuit must be restricted to specified limits; and, third, the frequency must remain constant.

Theory of Constant-Current Circuit

Temporarily, assume that the reactor and capacitor in figure 1 are ideal units with their currents 180 degrees apart, and that both currents are sinusoidal. The volt-ampere curve of the capacity I_c, and of the reactor I_x, are plotted in figure 2 without regard to the phase relation between the two currents. The line current then I_0 is the numerical difference between I_c and I_x. Thus, at any value of voltage E_1 the line current is the horizontal distance between the two volt-ampere curves. It is evident, therefore, that the volt-ampere curve for the reactor must be parallel to that of the capacitor if the resultant current remains constant between the limits of voltage of E_1 and E_1'. If this condition exists for the circuit in figure 1, the current through the impedance Z will remain constant while either the line voltage or the series impedance varies; or while both vary simultaneously.

A reactor with a volt-ampere curve similar to that shown in figure 2 can be obtained by a bridge-gap iron core, one type of which is shown in figure 3. It consists of an air gap in parallel with a section of steel which can be saturated while a relatively low density exists in the remainder of the core. The length of the air gap controls the slope of the straight portion of the volt-ampere curve, while the saturated section governs the flux density, or voltage, at which the straight portion begins. This fact is illustrated in figure 4 by a series of volt-ampere curves derived from various physical dimensions of the saturated steel and the air gap. Great flexibility is obtained from this type of core because magnetic shims may be inserted in the air gap to adjust the volt-ampere curve to its desired position. Naturally, a rather high leakage flux surrounds the air gap and it is desirable, therefore, to place the air gap in such a location that the nonlinear characteristics of the reactor will not be altered by the proximity of other magnetic materials.

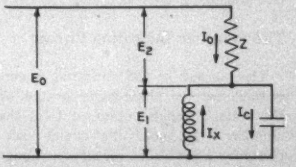

Figure 1. Parallel constant-current circuit

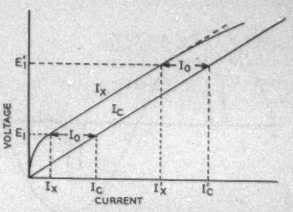

Figure 2. Current-regulating properties of nonlinear circuit

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The core of the reactor should be made of low-loss steel to maintain as nearly as possible a 90-degree phase angle between the voltage E_1 and reactor current I_x. In practical designs, however, neither the reactor current nor the capacitor current are displaced exactly 90 degrees from the voltage. The line current is not, therefore, the algebraic difference between the two currents, but the vector sum of them. Thus, there are some fundamental relations in the parallel circuit which cannot be shown without a vector diagram indicating conditions for successive increments of voltage, as in figure 5. The locus of the resultant current is not exactly the arc of a circle, but it lies between the arcs of two circles which are quite close together. Suppose the vector terminating at G represents the resultant current in the line when the voltage E_1 is applied. Although the voltage may be increased as much as 100 per cent to E_1', peak current, particularly during the reversing period when the counter electromotive force of the motor armature reduces the effective resistance of the tube circuit. It was found that on account of the dynamic breaking action of the tubes during the reversing period, the circuit in figure 8 was particularly suited for this regulating application because idling and overtravel of the motor was practically eliminated, therefore producing very accurate and sensitive control.

Complete Schematic Diagram

Figure 9 shows the schematic diagram for the complete control circuit, and a photograph of the regulator is shown in figure 10. From figure 9 may be seen that only one single adjustment, potentiometer P, is used. The purpose of this potentiometer is to increase the sensitivity when the difference between the paper color and the line color is slight with reference to the color characteristic of the phototube. An example of colors of this characteristic is a red line on white paper. If the line color is black, blue, green or brown, the equipment will operate satisfactorily with any potentiometer adjustment, and because variations in tube characteristics do not affect the operation, the regulator will operate without any further adjustments after once being installed.

the vector of the resultant current will fall somewhere between the two circular arcs CD and EF. Beginning at the point G, the current increase in magnitude to the point H; then decreases in numerical value to the point J; and thereafter increases while the voltage over this range is continually increasing from E_1 to E_1'. The power factor is leading at all times but approaches unity as the voltage E_1 increases.

The Constant-Current Transformer

The simple nonlinear circuit described above is the heart of a constant-current transformer with no moving parts. To make a more complete circuit, a transformer which delivers load at unity power factor is inserted in series with the capacitor-reactor unit as shown diagrammatically by figure 6. The reactor has been converted into an autotransformer without affecting its reactance characteristics and the higher secondary voltage permits a more economical capacitor to be used on common 110-volt circuits. The vector diagram for the complete circuit is shown in figure 7 for only one value of line voltage. The resultant power factor is leading, but obviously it is more nearly unity than the power factor of the parallel branch of the circuit alone; that is, δ is less than α. The vector diagram in figure 8 shows the relation between the three voltages E_0, E_1, E_2 with a resistance load across the transformer for two values of line voltage.

The circuit shown in figure 6 will maintain a constant I_s in the load circuit for a variable line voltage, a variable load impedance or a variation of both providing the reactor and capacitor operate over a range of voltage through which the volt-ampere curves are parallel. With a constant resistance load it can be shown that the most economical design from the viewpoint of minimum capacity in microfarads occurs when the variation in voltage E_1 is $\sqrt{2}$ times the variation in line voltage. Also when the line voltage is constant and the resistance load variable the value of E_1' in figure 2 should be $\sqrt{2}$ times the value of E_1. (See also figure 9.) The load may operate at either lagging, or leading power factor, providing the limits of voltage E_1 are not exceeded.

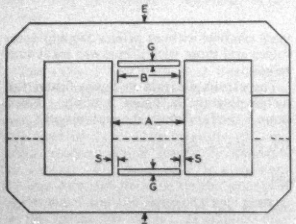

Figure 3. Bridge-gap core

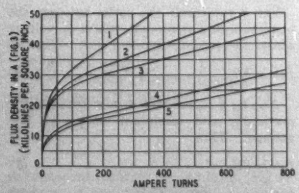

Figure 4. Calculated saturation curves for core shown in figure 3 (A = 1.375 inch)

Curve	g (inch)	x (inch)
(1)	0.062	0.125
(2)	0.125	0.125
(3)	0.187	0.125
(4)	0.187	0.062
(5)	0.25	0.062

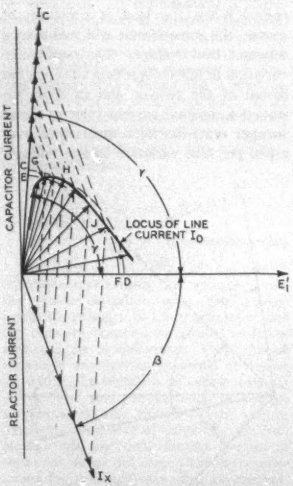

Figure 5. Successive vector diagram

Characteristics

The complete characteristics of a constant-current transformer supplying a resistance load are shown in figure 10. This unit was designed to operate on a line voltage varying between 105 and 125 volts and to deliver a constant current of one ampere at 25 volts. Between the specified limits of voltage, the output current actually varies from 1.04 amperes to 1.048 amperes.

The efficiency of the constant-current system varies between 50 per cent and 90 per cent. It is highest at the lowest value of line voltage and decreases in value as the line voltage increases. The power factor of the complete system is leading throughout the operating range for resistance load, and, like the efficiency, it is more nearly unity at the lower value of line voltage and decreases as the line voltage increases.

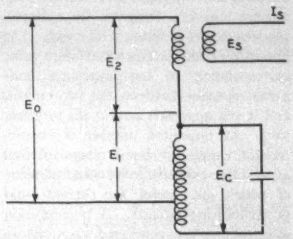

Figure 6. Constant-current-transformer circuit

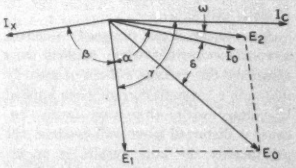

Figure 7. Vector diagram of constant-current transformer

Since reactance in the parallel circuit depends on frequency, it may be expected that the stable adjustment will be altered by changes in frequency and this is indeed the case. The volt-ampere curve of the reactor in figure 2 will swing toward the voltage axis as the frequency is increased, while that of the capacitor will swing toward the current axis as the frequency is increased. If a current-regulating circuit is designed to maintain a constant current at 60 cycles, it will gradually increase the line and load currents with increasing line voltage if the frequency is higher than 60 cycles. Conversely, if the frequency is less than 60 cycles the line and load currents will gradually decrease with increasing line voltages. Modern systems are so regulated that the variation in frequency may not exceed $1/8$ or $1/4$ of a cycle, and this is not great enough to injure the current regulating characteristics of a properly designed circuit. The characteristics of

one current stabilizing unit on 59, 60, and 61 cycles are illustrated in figure 11.

Generally speaking, this particular type of nonlinear circuit has many interesting characteristics depending on the relation between the capacitor and reactor volt-ampere curves. Suppose, for example, the two curves in figure 2 intersect. The line current will contain a maximum value corresponding to the maximum horizontal distance between the two curves, and it will approach zero at the intersection. An unlimited number of characteristic curves of line voltage plotted against line current can be obtained, some of which are useful for current- and power-limiting circuits. A phenomenon of instability is encountered when certain relations exist between the series and parallel components of the circuit, but a discussion of this phenomenon is beyond the scope of this paper.

A nonlinear circuit designed to deliver a constant current when applied to a sinusoidal line voltage will not necessarily maintain a constant current when applied to voltage with other wave forms, because a distorted wave will produce approximately the same results as an increase in frequency. By properly adjusting the reactor, however, a constant-current transformer may be made to operate on distorted voltage with reasonable satisfaction. Inherently, the current stabilizing system does not produce a badly distorted wave as indicated by the oscillogram of load and current in figure 12. The reactor and capacitor currents each contain a large third harmonic but their phase relation is such that they circulate around the parallel circuit and thereby are greatly restricted from flowing in the line. Transients existing in the line voltage will disturb the regulation in the load circuit, to a certain extent as indicated in figure 13. The oscillogram shows the line voltage and output voltage on the current stabilizer when the line voltage is rapidly changed from its minimum to maximum value, which in this case was from 85 to 125 volts.

The static constant-current circuit has been applied to numerous filament-control circuits for maintaining a constant filament current on variable-voltage circuits. When the load is constant, of course, the same circuit will maintain a constant load voltage. The permissible variation in line voltage depends upon the design of the reactor and in some instances a constant current (plus or minus two per cent) has been maintained over a 500 per cent variation in line voltage. This requires a rather extreme and bulky design. For lines having a total voltage variation of 50 per cent the static constant transformer is from twice to three times the physical size of an ordinary transformer with the same rating.

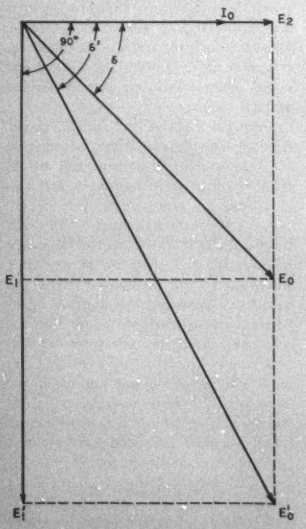

Figure 8. Vector diagram of ideal constant-current transformer for two values of line voltage

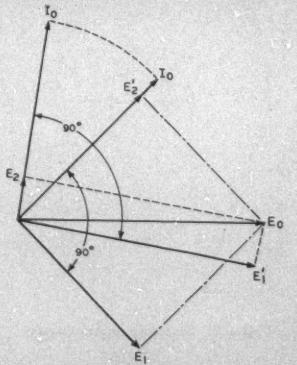

Figure 9. Vector diagram of constant-current transformer with constant line voltage and a variable resistance load

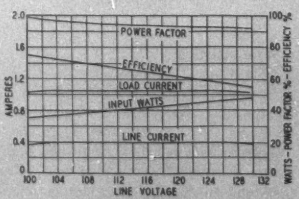

Figure 10. Characteristic curves of a 25-watt constant-current transformer

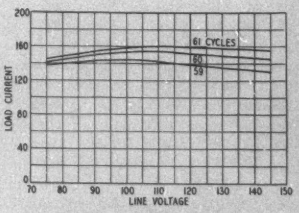

Figure 11. Frequency-regulation for a 150-watt, one-volt constant-current transformer

Appendix

Derivation of Formulas for Variable Line Voltage

A mathematical derivation of design formulas for a nonlinear circuit to operate on a variable line voltage and to maintain a constant current in a fixed, resistance load is given below. Sinusoidal currents and voltages are assumed and the losses in the reactor and capacitor are neglected. In all cases symbols without primes are minimum values and those with primes are maximum values.

The circuit diagram in figure 6 and the vector diagram in figure 8 apply. From figure 8 the fundamental equations are:

$$E_1^2 + E_2^2 = E_0^2 \tag{1}$$

and

$$(E_1')^2 + E_2^2 = (E_0')^2 \tag{2}$$

Subtracting (1) from (2), we have

$$(E_1')^2 - E_1^2 = (E_0')^2 - E_0^2 \tag{3}$$

Let k represent the ratio between the maximum and minimum values of voltage across the reactor-capacitor unit. That is,

$$E_1' = kE_1 \tag{4}$$

Also let d represent the ratio between the maximum and minimum values of line voltage. Thus,

$$E_0' = dE_0 \tag{5}$$

Substituting (4) and (5) in (3) for E_1' and E_0', respectively, and solving for E_1 we get,

$$E_1 = E_0\sqrt{\frac{d^2 - 1}{k^2 - 1}} \tag{6}$$

From equation (1),

$$E_2 = \sqrt{E_0^2 - E_1^2} \tag{7}$$

Substituting (6) in (7), we obtain

$$E_2 = E_0\sqrt{\frac{k^2 - d^2}{k^2 - 1}} \tag{8}$$

The capacitor must have the highest volt-ampere rating of any element in the circuit. The current passing through it is the sum of the exciting current and load current. It is desirable, therefore, to keep the size of capacitor at a minimum, by properly adjusting k with respect to d.

The volt-ampere rating (M) of the capacitor is independent of the voltage to which it is referred. That is, from figure 6,

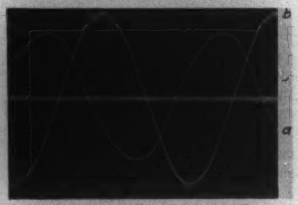

Figure 12. Wave form of load current of a constant-current transformer

a—Load current *b*—Line voltage

$$M = E_1 I_c \tag{9}$$

Where the current is referred to the low voltage side of the autotransformer.

Allowing I_c/I_0 (see figure 2) to be represented by the symbol P equation (9) becomes

$$M = E_1 P I_0 \tag{10}$$

The value P has a physical significance in that it represents the degree of current utilization. The capacitor is capable of supplying the current I_c in the line, but of this quantity I_x is taken to excite the nonlinear reactor which leaves I_0 available for output. The value of P is a constant for any core and depends on the sharpness of the knee, and the slope of linear portion of the saturation curve. It applies only at the minimum value considered.

The line current required (see figure 6) is

$$I_0 = \frac{W}{E_2 e} \tag{11}$$

where

W = load watts

e = efficiency of output transformer

Then substitute (11) in (10)

$$M = \frac{E_1 P W}{E_2 e} \tag{12}$$

and again substituting (6) and (8) in (12) we have

$$M = \frac{PW\sqrt{d^2 - 1}}{e\sqrt{k^2 - d^2}} \tag{13}$$

Since $I_c = 2\pi f C E_1 \times 10^{-6}$ the capacity required in microfarads is

$$C = \frac{M}{2\pi f E_1^2} \times 10^6 \tag{14}$$

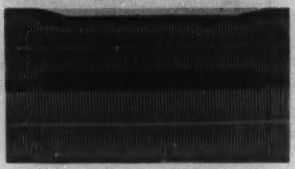

Figure 13. Effect of transients in constant-current transformer when the line voltage is rapidly changed (125 to 85 to 125 volts)

Above—Line voltage Below—Load voltage

Substituting (13) for the value of M in (14),

$$C = \frac{PW\sqrt{d^2 - 1}}{2\pi f E_1^2 e\sqrt{k^2 - d^2}} \times 10^6 \text{ microfarads} \tag{15}$$

Equation (15) indicates the size of the capacitor necessary if placed directly across the voltage E_1. If the capacitor is placed across the secondary of the autotransformer as in figure 6, it is necessary to replace E_1^2 by E_2^2. The maximum voltage that can be impressed safely on the capacitor is a limiting feature of the design and it must be incorporated in the design formulas. If we let E_c^1 be this maximum voltage allowable, then E_1^2 in equation (15) should be replaced by E_c^1/k. Equation (15), with this transformation, becomes

$$C = \frac{PW\,k^2\sqrt{d^2 - 1}}{2\pi f (E_c^1)^2 e\sqrt{k^2 - d^2}} \times 10^6 \text{ microfarads} \tag{16}$$

Equations (6), (8), and (16) are general equations representing the voltage across the reactor-capacitor unit, the voltage across the primary of the transformer, and the capacity required in parallel with the reactor or autotransformer. These general equations are derived in terms of known constants, the variation in voltage existing on the line, and the variation in voltage across the parallel branch of the circuit. There are a number of values for the constant k and an equal number of sizes of capacitor which will meet all of the requirements for maintaining a constant current. When equation (16) is differentiated with respect to k, the value of k corresponding to the minimum value of capacitor can be obtained. Before the equation is differentiated, however, it can be reduced to a more simple form. For any specific design, all quantities in (16) are constant except k; and all fixed terms except d can be included in a constant term Q. Thus,

$$C = \frac{k^2 Q\sqrt{d^2 - 1}}{\sqrt{k^2 - d^2}}$$

or

$$\left(\frac{C}{Q}\right)^2 = \frac{k^4(d^2 - 1)}{k^2 - d^2} = y \tag{17}$$

When y is a minimum, C must also be a minimum; therefore, y can be differentiated with respect to k.

We find thereby that C is minimum when

$$k = \sqrt{2}\,d \tag{18}$$

Substituting this value of k in equations (6), (8), and (16), respectively, we obtain the design equations for the most economical conditions.

$$E_1 = E_0\sqrt{\frac{d^2 - 1}{2d^2 - 1}} \tag{19}$$

$$E_2 = E_0\sqrt{\frac{d^2}{2d^2 - 1}} \tag{20}$$

$$C = \frac{WPd\sqrt{d^2 - 1}}{(E_c^1)^2 \pi f e} \times 10^6 \text{ microfarads} \tag{21}$$

Derivation of Formulas for Constant Line Voltage

The derivation of design formulas for a current-regulating circuit operating on a constant line voltage to supply a variable resistance load with a constant current is given below. The same assumption and nomenclature previously established apply to this circuit. The circuit diagram in figure 6 applies, but the vector diagram is shown in figure 9. The important difference between this circuit and the one previously analyzed is that the maximum value of reactor voltage, E_1^1, exists simultaneously with the minimum value of output transformer voltage, E_2, and vice versa. The symbol m is defined as

$$m = E_2^1/E_2$$

A procedure similar to that outlined above produces equations for minimum capacitance as follows:

$$k = \sqrt{2} \tag{22}$$

$$E_2 = E_0\sqrt{\frac{1}{2m^2 - 1}} \tag{23}$$

$$E_1^1 = E_0\sqrt{\frac{2(m^2 - 1)}{2m^2 - 1}} \tag{24}$$

and

$$C = \frac{I_0 E_0 P\sqrt{m^2 - 1}}{\pi f (E_c^1)^2\sqrt{2m^2 - 1}} \times 10^6 \text{ microfarads} \tag{25}$$

The above equations are sufficient to completely design a constant-current circuit with the exception of one factor; namely, the number of turns on the primary of the nonlinear reactor. The saturation curve for the core with flux density plotted against ampere-turns, of course, must be available; and a parallel line representing the capacitor volt-amperes must be drawn to the straight portion of the saturation curve. The horizontal distance between the two lines will represent ampere-turns and will correspond to the value in figure 2. The required line current I_0 can be determined easily for the design from the load requirement. If NI represents the horizontal distance between the saturation curve and the capacitor line in ampere-turns, and T represents the number of turns on the primary of the nonlinear reactor or autotransformer, the following equation applies:

$$T = \frac{NI}{I_0} \text{ (from curve)} \tag{26}$$

Analysis and Design of Harmonic Generators

By FREDERICK EMMONS TERMAN
MEMBER AIEE

HARMONIC generators such as used in radio transmitters are usually designed and adjusted on the basis of experience because the only analysis of their performance that has been available is a laborious point-by-point method of attack which is much too cumbersome to be practical in the general run of problems. In the present paper a new method of analyzing the harmonic generator is presented that involves a minimum of labor and at the same time has an accuracy entirely adequate for design purposes.

Voltage and Current Relations in Harmonic Generators

The circuit of a typical harmonic generator is shown in figure 1*a*, and is similar to a class-*C* amplifier circuit except for the fact that the plate tank circuit is tuned to a harmonic of the exciting voltage. When properly adjusted the instantaneous voltages, currents, and powers follow oscillograms such as indicated in figure 1. (The assumption of a sinusoidal alternating plate voltage in figure 1 is equivalent to saying that the Q of the plate tank circuit is high enough to make the voltage drop across it negligible for all alternating components except the desired harmonic.) The grid bias is made considerably greater than cutoff and sufficient signal voltage is applied to drive the grid somewhat positive. The result is that the space current flows in pulses having a relatively large peak amplitude but lasting for only a small fraction of the cycle. Such pulses have a large harmonic content, and the tank-circuit impedance is adjusted so that the desired component builds up a crest voltage across this circuit that is only slightly less than the plate-supply potential. This makes the minimum plate potential reached during the cycle quite small, as shown. The instantaneous power supplied to the plate circuit of the harmonic generator is equal to the plate-supply potential multiplied by the instantaneous plate current, as shown in figure 1*g*. This power is divided between loss at the plate of the tube and useful output delivered to the tank circuit in proportion to the instantaneous voltage drops existing across these parts of the circuit. Similarly the power loss at the grid at any instant equals the instantaneous grid current times the instantaneous grid-cathode potential, and the power that the grid exciting voltage must supply is likewise equal at any instant to the product of grid current and exciting voltage at that moment.

Simplified Analysis of Harmonic Generators

The oscillograms of figure 1 provide a means for making an exact analysis of the performance of the harmonic generator. These oscillograms can be drawn from the characteristic curves of the tube for any assumed voltages acting on the grid and plate electrodes. The practical usefulness of the result is, however, limited by the large amount of work required to plot the various curves point by point and to planimeter them to get averages.

An approximate analysis can be made by noting that the pulses of total space current in figure 1 appear upon inspection to approximate a section of a sine-wave pulse raised to some power of the order of 3/2. In screen-grid and pentode tubes, and in high-mu triodes, the space-current pulses are in fact almost exactly sections of such a sine pulse because of the fact that in these cases the plate voltage has little or no effect upon the total space current, which is then determined by a sine wave driving voltage of fundamental frequency. The analysis of harmonic generators under such conditions has already been outlined in earlier papers,[1,2] and makes use of curves giving the ratio I_0/I_m of average current to peak space current, and the ratio I_n/I_m of harmonic component of the space current pulse to peak value of pulse, in terms of the number of electrical degrees θ during which the space current flows. Such curves are given in figure 2.

In the case of harmonic generators employing ordinary triode tubes the space-current pulse does not have a shape that is exactly a section of a sine wave raised to some power. This is because the effective voltage producing the current pulse is a combination of fundamental-frequency and harmonic voltages, which obviously cannot follow exactly a section of a simple sine wave. The extent of the discrepancy depends upon the angle of current flow, the tube characteristics, etc. A practical procedure for analyzing the ordinary triode harmonic generator can, however, be worked out by assuming as a first approximation that the space-current pulse follows a section of a simple sine wave raised to a power, and then applying a correction to this result in order to take into account the discrepancy between the assumed and actual pulse shape.

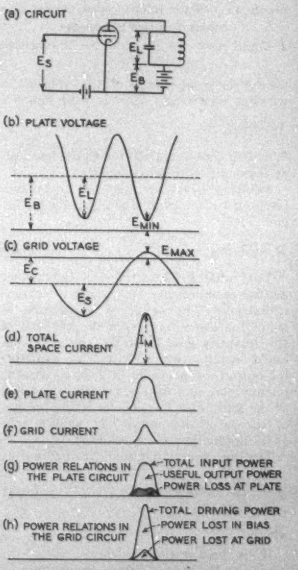

Figure 1. Circuit of typical harmonic generator, together with voltage, current, and power oscillograms

Curves giving the correction factor that must be applied to results obtained on the sine-wave section assumption are given in figure 3 for linear and square-law tube characteristics. The derivation of these curves follows.

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1. For all numbered references, see list at end of paper.

Mathematical Analysis

Notation

e_1 = net voltage available to produce electrostatic field in the vicinity of the cathode for the case of simple sine-wave pulse

e_h = net voltage available to produce electrostatic field in the vicinity of the cathode for harmonic generator case

$E_{max} = E_s - E_c$ = maximum instantaneous grid potential reached during cycle (see figure 1)

$E_{min} = E_B - E_L$ = minimum instantaneous plate potential reached during cycle (see figure 1)

θ = number of electrical degrees during which current flows (see figure 1) (based on fundamental frequency)

E_s = crest signal voltage (see figure 1)

$E_L = E_B - E_{min}$ = crest alternating voltage developed between plate and cathode (see figure 1)

E_c = grid bias

E_B = d-c plate-supply potential

μ = amplification factor of tube

n = harmonic involved

$E_m = E_{max} + \frac{E_{min}}{\mu}$ = crest amplitude of e_1 or e_h

$k = (E_L/\mu)/E_m$

$A = 1 - \cos\theta/2$

$B = 1 - \cos n\theta/2$

$C = \frac{B - A}{A} = \frac{\cos\theta/2 - \cos n\theta/2}{1 - \cos\theta/2}$

The net effective voltage available to produce a space-current pulse when the signal voltage and the output voltage are of the *same* frequency (class-*C* amplifier action), is

$$e_1 = \left(E_s - \frac{E_L}{\mu}\right)\cos\omega t - E_c + \frac{E_B}{\mu} \quad (1)$$

$$= E_m \frac{(\cos\omega t - \cos\theta/2)}{1 - \cos\theta/2} \quad (1a)$$

This voltage produces a space current that for positive e_1 is very nearly proportional to e_1^α, where α lies between one and two and is normally very close to 3/2. The space current is assumed to be zero when e_1 is negative.

The net effective voltage producing electrostatic field at the surface of the cathode when the alternating plate voltage E_L is a *harmonic* of the exciting voltage is

$$e_h = E_s \cos\omega t - \frac{E_L}{\mu}\cos n\omega t - E_c + \frac{E_B}{\mu} \quad (2)$$

A comparison of equations (1) and (2) shows that e_h fails to be a section of a simple sine wave exactly to the extent that the term $(E_L/\mu)\cos n\omega t$ fails to follow a sine-wave section of fundamental frequency in the interval $\omega t = -\theta/2$ to $\omega t = \theta/2$, (i. e., the interval *abc* in figure 4). The error involved in using the curves of figure 2 to give the space-current pulses is then caused by the discrepancy between the dotted and solid curves in figure 4, where the dotted curve corresponds to a wave of fundamental frequency coinciding with the actual harmonic curve at points *a*, *b*, and *c*.

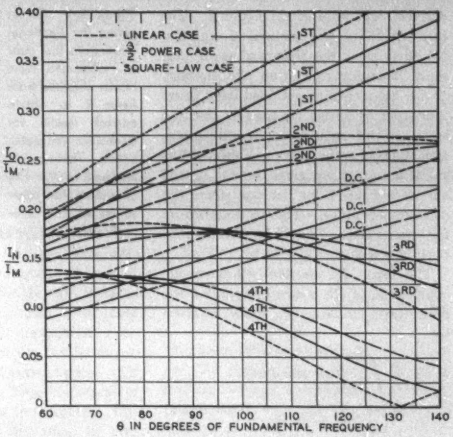

Figure 2. Curves giving the d-c and harmonic components of space-current pulses that are produced by an effective driving voltage that is a section of a simple sine wave

The magnitude of this error can be evaluated by taking the difference of the dotted and solid curves in figure 4. The equation of the solid (harmonic) curve in figure 4 is

$$e' = \frac{E_L}{\mu}\cos n\omega t \quad (3)$$

while the equation of the dotted (fundamental) curve referred to the same axis is

$$e'' = \left(\frac{E_L}{\mu} + \beta\right)\cos\omega t - \beta \quad (4)$$

where β represents the axis of the dotted curve as shown in the figure, and the two curves are assumed to coincide at *b*. The value of β is determined by the fact that the dotted curves must also pass through points *a* and *c*. That is

$$\frac{E_L}{\mu}\cos n\theta/2 = \left(\frac{E_L}{\mu} + \beta\right)\cos\theta/2 - \beta \quad (5)$$

Eliminating β in (4) by means of (5) gives

$$e' = \frac{E_L}{\mu}\left\{\left(\frac{1 - \cos n\theta/2}{1 - \cos\theta/2}\right)\cos\omega t - \frac{\cos\theta/2 - \cos n\theta/2}{1 - \cos\theta/2}\right\} \quad (6)$$

$$= kE_m\left\{\frac{B}{A}\cos\omega t - C\right\} \quad (7)$$

where k, E_m, A, B, and C are as defined in the table of notation.

The difference $e' - e''$ then gives the error in the net effective voltage available to produce space current that results by assuming that the effective voltage producing the space current pulses is a section of a simple sine wave. This difference is

$$D = kE_m\left\{\cos n\omega t - \frac{B}{A}\cos\omega t + C\right\} \quad (8)$$

Here D is the amount by which the actual shape of the pulse for the case of *n*th harmonic generation is *less* (note negative sign of E_L in equation 2) than the effective voltage that would be acting if the pulse was determined by a simple sine-wave section of same θ and same maximum value. As a consequence, the difference term D given by equation (8) must be *subtracted* from the pulse obtained on the assumption of a sine-wave section in order to obtain the true amplitude.

In the case of a tube having a linear characteristic, the space current is proportional to the equivalent voltage producing electrostatic field in the vicinity of the cathode. Hence the error in the average or d-c component of the total space current made by assuming a section of a simple sine wave is equal to the average of D in equation (8) over the interval θ. Assuming for convenience that $E_m = 1$, then the average D_0 of D is

$$D_0 = \frac{1}{2\pi}\int_{-\theta/2}^{\theta/2} D\, d(\omega t)$$

$$= \frac{k}{\pi}\left\{\frac{\sin n\theta/2}{n} - \frac{B}{A}\sin\frac{\theta}{2} + C\frac{\theta}{2}\right\} \quad (9)$$

The average of equation (1) as a function of the angle of flow θ has been previously

derived, and is given in figure 2. The ratio of D_0 to the average of equation (1) then gives the fractional error that must be subtracted from the average or d-c space current obtained from figure 2 in order to correct for the fact that the space-current pulse is not exactly a section of a simple sine wave. Values of this fractional error are given by the dotted curves in figure 3 for the case where the constant k is unity. The fractional errors for other values of k will be directly proportional to k.

The error D_n in the nth-harmonic component of the space current for the linear case, assuming E_m unity, is given by

$$D_n = \frac{1}{\pi}\int_{-\theta/2}^{\theta/2} D \cos n\omega t \, d(\omega t)$$

$$= \frac{2k}{\pi}\left\{\frac{1}{4n}(n\theta + \sin n\theta) - \frac{B}{A}\left(\frac{\sin (n-1)\theta/2}{2(n-1)} + \frac{\sin (n+1)\theta/2}{2(n+1)}\right) + \frac{C}{n}\sin\frac{n\theta}{2}\right\} \quad (10)$$

The fractional error that must be subtracted from the value of nth harmonic obtained from figure 2 on the assumption of a sine-wave pulse is then the result obtained from equation (10) divided by the nth-harmonic component of the space-current pulse on the assumption of a simple sine-wave section as obtained from figure 2. Values of this ratio are given by the dotted lines of figure 3.

Consider next the case where the total space current is proportional to the square of the effective voltage producing electrostatic field near the cathode. The true value of space-current pulse is then proportional to $(e_1 - D)^2 = e_1^2 - 2e_1D + D^2$. The error involved in assuming that the pulse has a shape based upon a section of a sine wave is obviously $2e_1D + D^2$. However if the error D is not large compared with e_1, as is the case under practical conditions, then D^2 can be neglected and the error becomes very nearly $2e_1D$. The error D_0' in the average or d-c component of the total space current is hence (assuming E_m is unity)

$$D_0' = \frac{1}{2\pi}\int_{-\theta/2}^{\theta/2} 2e_1 D$$

$$= \frac{1}{\pi}\int_{-\theta/2}^{\theta/2} \frac{\cos\omega t - \cos\theta/2}{1 - \cos\theta/2} D\, d(\omega t)$$

$$= \frac{2k}{\pi A}\left\{\frac{\sin (n-1)\theta/2}{2(n-1)} + \frac{\sin (n+1)\theta/2}{2(n+1)} - \frac{B}{4A}(\theta + \sin\theta) + C\sin\theta/2\right\} - \frac{2D_0\cos\theta/2}{A} \quad (11)$$

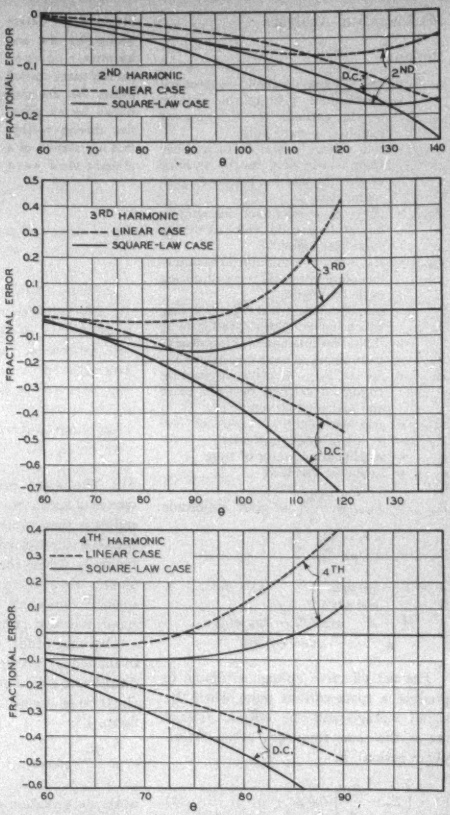

Figure 3. Curves giving the fractional corrections that must be subtracted from results obtained from figure 2 to obtain correct results for harmonic-generator action. These curves assume k = 1. The correction for other values of k is proportional to k

The ratio of this to the d-c value obtained from figure 2 for a square-law characteristic is then the fractional error involved in assuming that the pulses in the harmonic generator are based on the square of a section of a simple sine wave. Values for this fractional error are given by the solid lines in figure 3. In a similar manner the error D_n' in the nth harmonic component of the total space current that is involved in assuming that the pulse is the square of a section of a simple sine wave is

$$D_n' = \frac{1}{\pi}\int_{-\theta/2}^{\theta/2} 2e'D\cos n\omega t\, d(\omega t)$$

$$= \frac{2}{\pi}\int_{-\theta/2}^{\theta/2} \frac{\cos\omega t - \cos\theta/2}{1 - \cos\theta/2} D \times \cos n\omega t\, d(\omega t)$$

$$= \frac{2k}{\pi A}\left\{\sin\frac{\theta}{2} + \frac{\sin(2n-1)\theta/2}{2(2n-1)} + \frac{\sin(2n+1)\theta/2}{2(2n+1)} - \frac{B}{A}\left[\frac{\sin n\theta/2}{n} + \frac{\sin(n-2)\theta/2}{2(n-2)} + \frac{\sin(n+2)\theta/2}{2(n+2)}\right] + C\left[\frac{\sin(n-1)\theta/2}{(n-1)} + \frac{\sin(n+1)\theta/2}{(n+1)}\right]\right\} - \frac{2\cos\theta/2}{1-\cos\theta/2} D_n \quad (12)$$

The ratio of the error given by equation (12) to the nth-harmonic component of the space current for the square-law char-

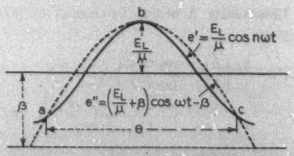

Figure 4. Approximation of a section of a sine-wave section of harmonic frequency by a section of a sine wave of fundamental frequency

acteristic as given in figure 2 is then the fractional error. This is plotted in figure 3 for various harmonics as a function of angle of current flow.

Calculation of Harmonic-Generator Performance

It is now possible to calculate the performance of the harmonic generator for any given set of operating conditions. In doing this the operating condition is defined in terms of the angle of current flow θ, maximum grid potential E_{max}, minimum plate potential E_{min}, grid bias, and plate-supply voltage. The first step is to determine the peak total space current I_m and peak grid current I_{gm} corresponding to the given values of E_{max} and E_{min}, by using characteristic curves as supplied by the tube manufacturer. The d-c and harmonic components I_0 and I_n of the total space current for this value of I_m are then obtained from figure 2, assuming that the current pulse is a section of a sine wave raised to a power of the order of 3/2. The next step is to determine from figure 3 the fractional corrections for the d-c and harmonic components, interpolating between the dotted and solid curves according to the exponent used in connection with figure 2. These fractional corrections are then multiplied by the value of k for the case at hand, and the necessary corrections determined, and subtracted from the results of figure 2 to give the components of the actual pulse of total space current.

The division of these components between grid and plate electrodes can be determined by the fact that when secondary electron emission at the grid is not excessive (as is normally the case), the pulse of grid current can be considered as approximating a section of a sine wave of fundamental frequency that has been squared.[3] The angle of current flow θ_g for this pulse can be calculated from the equation

$$\cos \theta_g/2 = \frac{E_c}{E_s} \tag{13}$$

The d-c, fundamental-frequency, and harmonic-frequency components of the grid current can now be evaluated in terms of θ_g and the peak grid current, with the aid of figure 2. The d-c plate current is then the d-c component of the total space current minus the d-c grid current, and the harmonic component of the plate current is the harmonic component of the total space current minus the harmonic component of the grid-current pulse. (If secondary emission is large the shape of the grid current pulse is modified. Under such conditions the effect of grid current can be evaluated roughly by estimating the ratio of d-c grid current to d-c component of total space current on the basis of previous experience, and then assuming that the fundamental and harmonic components of the grid current are twice the d-c value.)

It now remains to determine the power relations. The power supplied to the plate circuit is the d-c component of the plate current multiplied by the plate-supply voltage, while the power output delivered to the tank circuit is half the harmonic component of the plate current multiplied by the crest alternating plate-cathode voltage E_L. The ratio of these two powers gives the plate efficiency, and their difference gives the dissipation at the plate. The ratio of the alternating plate-cathode voltage E_L to the harmonic component of the plate current equals the load impedance that the tank circuit must supply.

The grid bias can be calculated by the following formula derived from conventional theory:

$$\text{Grid bias} = E_c = \frac{E_B(1 - \cos n\theta/2) + E_{min}\cos n\theta/2}{\mu(1 - \cos \theta/2)} + \frac{E_{max}\cos \theta/2}{1 - \cos \theta/2} \tag{14}$$

The peak exciting voltage is $E_c + E_{max}$, and the grid driving power is this peak exciting voltage multiplied by half the fundamental-frequency component of grid current.

An example illustrating the details of the calculation procedure is given in the appendix.

Discussion of Factors Involved in Design of Harmonic Generators

The most important operating characteristics of a harmonic generator are the harmonic power delivered to the tank circuit, the power dissipation at the plate of the tube, and the driving power. The design factors available to control the performance are the angle of current flow, the minimum instantaneous potential E_{min} reached by the plate, and the maximum instantaneous potential E_{max} reached by the grid. The influence of these design factors on the performance of a harmonic generator is illustrated in figure 5. A study of this figure, together with figures 2 and 3, brings out the salient features involved in harmonic generator behavior. *First*, for a given peak space current* and harmonic, the power output will be maximum when the angle θ of current flow based on the fundamental frequency is approximately $260°/n$. The maximum is not critical however, and angles of flow differing from this by as much as ± 40 per cent give good output. *Second*, the plate efficiency of the harmonic generator is increased by reducing the angle of current flow to a value smaller than that giving maximum output because this causes the d-c component of the total space current, and hence the input power, to decrease faster than the output falls off. It is also to be noted that the plate efficiency of a harmonic generator will be considerably less than for the corresponding class-C amplifier unless the angle of flow is appreciably less than the value for maximum output. *Third*,

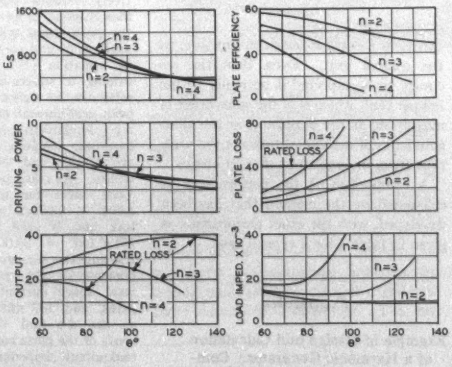

Figure 5. Curves showing the performance of a typical tube operated as a harmonic generator under various conditions

* The allowable peak space current is determined by the cathode emission, assuming a reasonable factor of safety. Manufacturers have not, however, established peak current ratings for their tubes. Until this is done the designer may assume that the peak current rating approximates four to five times the sum of d-c plate and grid currents obtained with recommended class-C telegraph operation.

the values of E_{min} and E_{max} not only must be such as to draw the maximum allowable space current, but should also normally have a ratio E_{max}/E_{min} somewhat less than is customary in class-*C* amplifiers in order to keep the grid current, and hence the driving power, low in spite of the large exciting voltage required. *Fourth*, the driving power increases as the angle of current flow is reduced, and becomes excessive at angles of flow as small as 60 to 70 degrees. Because of this the driving power is as much a limiting design factor in harmonic generators as is the plate loss and power output. *Fifth*, the load impedance that the tank circuit must supply is greater for harmonic generators than for the corresponding class-*C* amplifier, and becomes greater the higher the order of harmonic. This results from the fact that for proper operation the voltage across the tank circuit is independent of the harmonic whereas the output power is less the higher the harmonic. With a given effective tank circuit Q this means that the L/C ratio should be higher for harmonic generators than class-*C* amplifiers. *Sixth*, the output power obtainable in second harmonic generation is about $^2/_3$ of the output that the same tube will develop as a class-*C* amplifier, and for higher harmonics the output is roughly inversely proportional to the order of the harmonic. *Seventh*, the fact that output goes down and driving power goes up as the order of the harmonic is increased makes it unwise to attempt harmonic generation above the third or fourth harmonic under ordinary conditions, since with fifth harmonic operation the driving power can be expected to be of the same order of magnitude as the power output.

Accuracy

The accuracy of the analysis that has been developed for harmonic generators is entirely adequate for ordinary design purposes. The principal assumption involved is that the total space current of the tube is proportional to $(E_g + E_p/\mu)^\alpha$, where μ and α are constants. If the values of μ and α are taken for conditions corresponding to a fairly large total space current experience[3] shows that the errors introduced by considering α and μ constant are quite small even though α and μ vary appreciably as cutoff is approached. The method of handling grid current also involves some approximation, but this is unimportant, particularly if there is no secondary emission. In any case the action of grid current is in itself only a second-order effect and therefore need not be determined with precision. The neglect of the D^3 term in obtaining equations (11) and (12) also introduces some error, particularly when θ exceeds $260°/n$, but since the values of k encountered in practice are usually less than 0.5, the error in the actual pulse of total space current from this approximation will reach five per cent only in the most unfavorable cases.

Under ordinary conditions the analysis can be expected to give calculated plate loss, output power, and plate current, correct within about five per cent unless the angle of flow is exceptionally large for the harmonic involved, or unless there is excessive secondary electron emission at the control grid. Even then the accuracy to be expected is normally within ten per cent, which is of the same order of magnitude as the variations in the characteristics of individual tubes of the same type from the published characteristics.

Table I. Agreement Between Calculated and Exact Harmonic-Generator Performance

Conditions: Type 204-*A* tube, E_B = 1,500, E_{max} = 250, E_{min} = 375, I_m = 1.26 amperes, peak grid current = 225 milliamperes, θ = 100 degrees, n = 3, E_c = 751 volts

	Approximate	Exact
D-c plate current (milliamperes)	189	196
D-c grid current (milliamperes)	27	20
Power input (watts)	284	294
Power output (watts)	105	102
Driving power (watts)	26	19
Plate loss (watts)	179	192
Plate efficiency (per cent)	37	35

A comparison of the performance as calculated by the method that has been developed, with the exact performance is given in table I for a typical case.

Appendix

Example of Design and Calculation of a Harmonic Generator; Comparison With Exact Performance

In order to show how the above analysis is applied, assume that it is desired to obtain third harmonic generation from a type 204-*A* tube operating at 1,500 volts, having μ = 23, and a normal rated plate dissipation of about 200 watts. This tube is not the most satisfactory one for demonstrating the accuracy of the method of analysis that has been developed because the published characteristics of the 204-*A* tube show more secondary electron emission at the grid than do most air-cooled tubes. However, it is selected because it is one of the few tubes for which the published characteristics are sufficiently complete to permit checking of the approximate analysis by exact point-by-point calculations. Most of the so-called "complete" characteristic curves of transmitting tubes found in tube manuals are not extended to high enough plate potentials to cover the full operating range commonly used in harmonic generators.

The first step in the design is the selection of a suitable peak space current and corresponding values of E_{min} and E_{max}. Reference to the data supplied by tube manufacturers indicates that I_m = 1,260 milliamperes will be satisfactory, and that this could be obtained by E_{min} = 375, E_{max} = 250. With this combination the peak grid current will be 225 milliamperes, which is small enough to keep the driving power low, and yet at the same time E_{min} will be small compared with the plate-supply voltage.

The next step is the selection of a value of θ. From the discussion given in the paper, combined with an examination of figure 2, it appears that θ = 100 degrees would be reasonable. With this value of θ, and assuming a 3/2-power law, figure 2 then gives I_0/I_m = 0.161, and I_n/I_m = 0.177. The fractional corrections that figure 3 indicates would be applied to these for a 3/2 law and for k = 1 are −0.33 for the d-c term and −0.060 for the third-harmonic component. However, as k is $[(1{,}500 - 375)/23]/250$ = 0.20 the actual corrections are −0.065 and −0.012, respectively. The d-c and third-harmonic components of the total space current are then 1,260 × 0.161 (1+0.065) = 216 milliamperes, and 1,260 × 0.177 (1 + 0.012) = 226 milliamperes, respectively. From equation (14) the grid bias is found to be 751 volts, which makes the peak signal voltage 1,001 volts. The angle θ_g of grid-current flow is then given by equation (13) as 82.8 degrees. Assuming a square-law grid-current pulse, reference to figure 2 shows that for a peak grid current of 225 milliamperes, the d-c, fundamental-frequency, and third-harmonic components of the grid current are 27, 52, and 39 milliamperes, respectively. As the peak signal voltage is 1,001 volts the grid driving power is 1,001 × 0.052/2 = 26 watts. If grid-leak bias is used the leak resistance is 751/0.027 = 28,000 ohms. Next, subtracting the d-c and third-harmonic components of the grid current from the total space current, gives 189 milliamperes, and 187 milliamperes, respectively, as the d-c and third-harmonic components of the plate current. This calls for a tank-circuit impedance of 1,125/0.187 = 6,000 ohms. The power input to the plate is 284 watts while the third-harmonic power delivered to the tank circuit is 0.187 × 1,125/2 = 105 watts. The plate efficiency is hence 37 per cent while the plate dissipation is 179 watts. Inasmuch as this loss is slightly less than the rated value for normal operation, the assumed E_{min}, E_{max}, and θ represents a suitable operating condition.

The performance of this harmonic generator for the same E_B, E_{min}, E_{max}, and E_c has been calculated exactly by graphical integration of curves such as shown in figure 1 drawn on the basis of tube characteristics given in the tube manual. The results are given in table I, and show

The Electric Strain Gauge

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MANY new developments have grown out of the vibration recorder[1] originally described before the AIEE in 1926. One of the first of these developments resulted in apparatus for recording transient pressures electrically.[4] This has been used to measure transient pressures in switchgear apparatus, transformers, water wheels, steam turbines, gasoline engines, refrigerators, and in other places. Another is the electric gauge[5,18] which has many applications. It is used for the most accurate gauging of production parts in machine shops and inspection rooms, also it is widely used in steel mills for continuous gauging of strips as they are being rolled, for controlling their thickness, for measuring the tension in the strip[19] and the pressure applied to the mill rolls. Another application is the measurement of the thickness of paint, enamel, or other nonmagnetic coatings over steel.[13]

The electric strain gauge is an instrument for measuring mechanical strains electrically. Electrical, mechanical, and civil engineers have used it very successfully. It has proved its value in the study of stresses in railroad tracks and in bridge members as locomotives pass over them and in determining the lateral thrust produced by the axles of the locomotives.[14]

Electric-locomotive designs have been greatly influenced by the results obtained from these gauges. It is equally useful in measuring the strain in machine parts when they are subjected to stress.

Originally these developments used an oscillograph to produce records in which a 500-cycle wave was modulated, figure 5 (*a*). The envelope of the wave showed the variations in the quantity being recorded. In order to obtain accuracy the deflections were necessarily large and the number which could be recorded on a single film without overlapping each other was correspondingly small.

The record obtained from the electric strain gauge is a single-line trace of the varying strain in the part to which the gauge is attached. Several of these curves can be recorded on a film, figures 5 (*b*) and (*c*), even though the deflections are comparatively large. This makes it possible to obtain greater sensitivity without introducing difficulty in interpreting the records.

The electric strain gauge, shown in figures 1 and 2, has a circuit fundamentally the same as that of the vibration recorder.[1] The four arms of an a-c bridge circuit, figure 3, contain, respectively, a strain-gauge head, a balancing unit and two coils of a differentially connected transformer. The two differential transformer coils will have zero drop across them when the strain-gauge head and the balancing unit have about the same air gaps. The air gap of the balancing unit remains fixed while that of the strain-gauge head varies according to the strain in the piece of apparatus under investigation. The voltage drop across the differential transformer varies with the changes in the air gap of the strain-gauge head and the deflections of the oscillograph galvanometer are proportional to these.

The strain-gauge head *A*, figure 1, is shown mounted on a test bar and its balancing unit *B* is at the right. *C* is a mounting fixture used to align the gauge head while attaching it to the work. Changes in length of the test bar vary the air gap between the two parts of the magnetic circuit of the gauge head. In figure 2 is shown a four-circuit power unit for use with four strain-gauge heads and their balancing units. The four oscillograph galvanometers and the necessary 2,000-cycle excitation are also connected

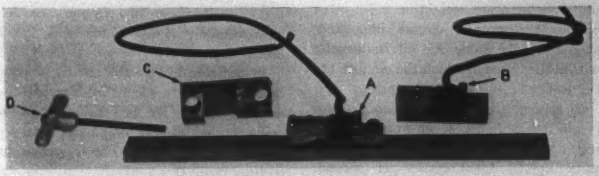

Figure 1

A—Strain-gauge head mounted on a test bar
B—Balancing unit
C—Attaching fixture

Figure 2. Power unit for use with four strain-gauge heads

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1. For all numbered references, see list at end of paper.

an agreement entirely satisfactory for design purposes even in spite of the fact that the 204-*A* tube has considerable secondary electron emission at the control grid. This secondary emission makes the grid-current pulse more peaked than a square law, thereby reducing the d-c grid current below the calculated value while raising the d-c plate current, but without affecting the third-harmonic component of grid and plate currents appreciably. If it were not for these effects of secondary emission the agreement between calculated and exact results would be within three per cent, but even as it is the errors in calculated power output and plate loss are less than seven per cent.

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3. THE EFFECT OF GRID CURRENT FLOW UPON THE DYNAMIC CHARACTERISTICS OF POWER AMPLIFIERS, W. L. Everitt and Karl Spangenberg. IRE *Proceedings*, volume 26, May 1938, page 612.

to the power unit, producing a record of four strains simultaneously. For convenience in operating in the field a 2,000-cycle generator driven by a 12-volt motor is operated from a 12-volt storage battery, figure 3. Where a power supply is available, the 2,000-cycle generator can be driven by a standard motor.

The principal difference between the old vibration recorder and the new strain gauge lies in the oscillograph galvanometer circuit. This circuit includes, in addition to the galvanometer, a copper-oxide rectifier, a 2,000-cycle filter, and a 4,000-cycle filter. The galvanometer circuit must have a low impedance for all frequencies within the range in which mechanical phenomena occur, as for example, from one to 1,000 cycles per second. Most mechanical apparatus on which strain gauges would be used will have natural frequencies well within this range.

In order to obtain relative values for the various frequencies to be recorded, it is necessary to use a galvanometer filter circuit that will give all frequencies approximately the same weighting. In other words, the output circuit impedance should be the same for all frequencies within the range in which the circuit is to be used.

A typical frequency-impedance curve is plotted in figure 4, showing that the impedance remains approximately the same up to 1,000 cycles per second, ranging from 125 to 180 ohms. Mechanical deflections in the range from 1,500 cycles to 2,200 cycles will be recorded at greatly reduced values as these fall within the resonant zone of the 2,000-cycle filter, which is designed with a high impedance to eliminate the 2,000-cycle excitation of the generator. A 4,000-cycle filter circuit is used to eliminate the 4,000-cycle ripple.

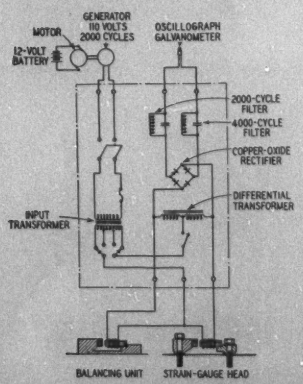


Figure 3. Schematic diagram of electric strain gauge

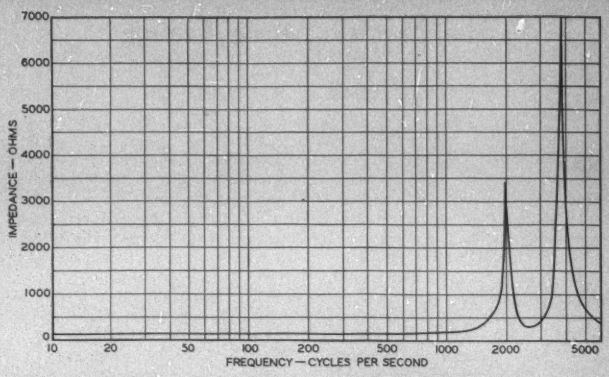


Figure 4. Frequency-impedance curve of oscillograph-galvanometer filter circuit of electric strain gauge

The two high-impedance peaks in figure 4 come at 2,000 cycles and at 3,800 cycles per second, where the circuit is in resonance for the purpose of eliminating the excitation frequencies. The impedance at these two frequencies are approximately 3,400 ohms and 7,000 ohms, respectively.

In order to clarify the results of producing a pure d-c record from an a-c excitation source, let us consider what is going on within the oscillograph-galvanometer filter circuit. The copper-oxide rectifier receives a 2,000-cycle alternating current for its input, which contains equal amplitudes for each of the individual half cycles provided there is no mechanical disturbance being investigated. When mechanical transients occur, the individual half cycles vary in amplitude in proportion to the disturbances which are being measured. In other words, the 2,000-cycle carrier wave is modulated by the mechanical phenomena. The copper-oxide rectifier receives this modulated 2,000-cycle wave and has for an output a modulated pulsating wave. The pulsations from the rectifier are eliminated from the galvanometer circuit by the 2,000-cycle and the 4,000-cycle filters, thus producing a d-c deflection.

A Fourier Series analysis of the rectifier pulsations shows a d-c component, a fundamental of 4,000 cycles, a lower frequency component of 2,000 cycles, and harmonics higher than 4,000 cycles. An oscillographic analysis of the galvanometer circuit shows that the galvanometer itself produces considerable mechanical damping as the natural frequency of the supersensitive galvanometer used is approximately 1,200 cycles per second. The 4,000-cycle filter when used alone leaves a 2,000-cycle ripple on top of the d-c deflection. This 2,000-cycle ripple comes from the rectifier and the magnetic pick-up in the circuit. The 4,000-cycle filter and the 2,000-cycle filter, together with the mechanical damping of the galvanometer, produce a d-c deflection which is practically free from alternating current.

The oscillogram, figure 5 (*b*), shows a record of the mechanical transient which occurred in a test bar when subjected to a sudden blow. Curve *B* shows this transient as recorded by the strain gauge. Curve *C* shows the corresponding 2,000-cycle transient supplied to the rectifier. Curve *A* is a 60-cycle timing wave. Strain-gauge records such as curve *B* can be easily identified even when they overlap each other. It is possible to record six such curves simultaneously when using a six-element general-purpose oscillograph. Figure 5 (*c*) shows five records which can readily be distinguished from each other at all points.

The strain-gauge head *A*, figure 1, must be calibrated very accurately in order to measure the small changes in length of the part under test. For this purpose it is mounted at *A* on a calibrating stand, figure 6, just as in actual use, with the balancing unit *B* in the second leg of the bridge circuit, figure 3, of which the remaining two legs are in the power unit, figure 2. It is customary to make this calibration in ten-thousandths of an inch (0.0001-inch steps) although less accurate calibrations are sometimes sufficient. An electric gauge *E*, figure 6, is used with its power unit *F* and indicating microammeter *G* as a calibrating

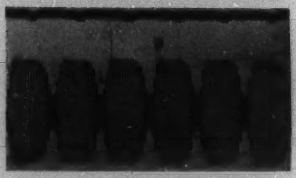


Figure 5a. A modulated 500-cycle record

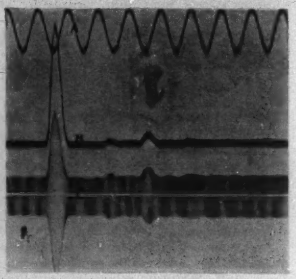


Figure 5b. Strain-gauge record

A—Timing wave, 60 cycles
B—Mechanical transient, impressed on the electric strain-gauge circuit
C—2,000-cycle a-c input to copper-oxide rectifier

medium. A 2,000-cycle power supply is used for excitation and an oscillograph galvanometer for recording in order to be able to apply the calibration to rapid changes which may occur while the strain gauge is being used. The calibration is made by taking readings of oscillograph deflections corresponding to a number of definitely spaced settings of the strain-gauge head. The indicating instrument *G*, figure 6, which is used with the electric gauge *E*, gives a full-scale deflection for 1/1,000 inch movement at the strain gauge, a magnification of 5,000 to one. Provision is made on the calibrating stand for comparing the electric

Table I. Calibration of Strain-Gauge Head

Master Gauge Blocks, Nominal Thickness (Inches)	Thickness (Inches)	Micro-amperes	Oscillograph Galvanometer Deflections (Millimeters)
0.1000	0.10000	100	11
0.1001	0.10006	121	15
0.1002	0.10019	157	22.5
0.1003	0.10028	187	28.5
0.1004	0.10036	205	32
0.1005	0.10048	250	41
0.1006	0.10060	288	48.5
0.1007	0.10068	312	53.5
0.1008	0.10079	349	61
0.1009	0.10090	388	68.5
0.1010	0.10099	423	75.5

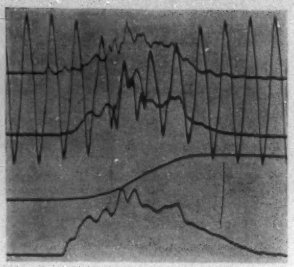


Figure 5c. Simultaneous records using electric strain gauges and vibration recorder

gauge directly with accurate thickness standards.

After calibrating the strain-gauge head on the stand, it can be moved to a test position without changing its calibration when its air gap is reset to give the same oscillograph deflection.

A typical calibration of a strain-gauge head is shown in table I. This calibration was taken with air gaps of approximately 0.010 inch in the strain-gauge head and balancing unit. It is here seen that a strain of 1/100,000 inch produces an oscillograph deflection which is easily read. Corresponding calibrations with larger air gaps can be taken if less sensitivity is desired in order to cover a wider working range.

The calibrations of table I are made statically, but they can be applied to transient measurements over the frequency range for which the instrument was designed. The variations in air gap of the strain-gauge head produce changes in impedance of that branch of the bridge circuit which are independent of their rate of change and should be recorded correctly if they are within the frequency range of the electric gauge and of the oscillograph galvanometer used. In order to obtain high current sensitivity a supersensitive oscillograph galvanometer is used for recording. This can be used up to at least 500 or 600 cycles per second without correction. A transient such as that shown in curve *B*, figure 5 (*b*), was over in $^1/_{30}$ second so that it was well within the working range of the oscillograph galvanometer. Errors due to change of damping of the oscillograph galvanometer with change of temperature are practically eliminated due to the fact that the comparatively low frequency of the modulated wave is recorded instead of the higher carrier frequency.

If only static or slowly varying strains are to be recorded, a carrier frequency lower than 2,000 cycles is satisfactory de-

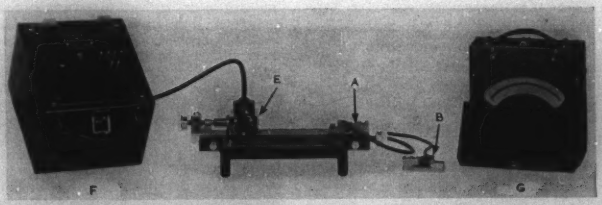
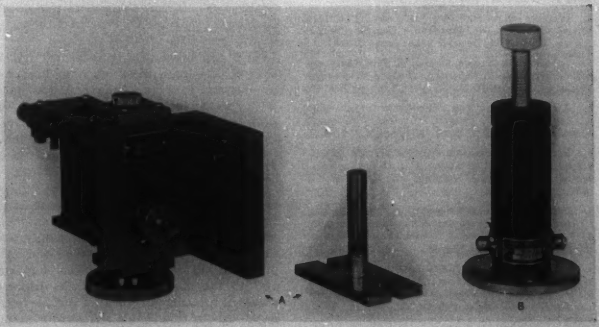


Figure 6 (above). Strain gauge calibrating equipment (power unit at left, calibrating stand and gauge heads in center, indicating instrument at right)

Figure 7 (below)

A—Travel recorder detector
B—Balancing unit



pending upon the rate of change of the stress. An indicating instrument can be substituted for the oscillograph galvanometer to show the magnitude of static strains only.

In connection with the measurement of strain, it is frequently desirable to determine the relative movement of parts. A travel-recorder detector, designed to measure deflections up to one inch, is shown in figure 7 together with its balancing unit. These are substituted for the strain-gauge head and balancing unit of figure 3, producing a record comparable with that from the strain gauge. It is used with the oscillograph when very rapid changes are to be recorded or with an indicating instrument to show slower movements.

The armature, shown in the middle of figure 7 is mounted on the moving part and the frame of the detector on the stationary part so that one moves with respect to the other. The deflections on the oscillograph film are directly proportional to the mechanical motions and are unidirectional with respect to the electrical zero.

Summary

The electric strain gauge can be used to record accurately strains as low as 0.00001 inch, whether these are static or are oscillatory at frequencies up to at least 500 cycles per second, and the single-line trace allows several measurements to be recorded simultaneously.

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Discussion

C. M. Hathaway (General Electric Company, Schenectady, N. Y.): This paper is intended by its authors to serve as a progress report to the Institute and it should be welcomed because a great deal has been accomplished since the original presentation by A. V. Mershon, one of the co-authors of the present paper, in 1926, in a paper entitled "Vibration Recorder for Electrically Measuring and Recording Small Mechanical Movements."

Although the device originally described by Mr. Mershon has received numerous modifications since that time as its application has been extended in many different directions, the same fundamental circuit still survives. This present paper described the extension of the application of the gauge to measurements at higher frequency, the addition of a filter to provide a more desirable type of record as well as a more accurate one, and the application of the gauge to the measurement of strain.

The applications of the electric gauge since its original conception have been numerous, and they are, I believe, just as interesting to engineers in all branches of our profession, so I will present a little historical sketch of its development from infancy to the present time, and describe some of its interesting and more recent applications.

The fundamentals of the electric gauge were first worked out in order to measure the motion of hydraulic gate valves under water. The principle was applied shortly thereafter to the measurement of transient pressures in oil-circuit-breaker housings and to the measurement of the displacements of rotating parts within turbine housings. About this time a refrigerator manufacturer was in need of an accurate gauge for the production measurement of compressor parts having tolerances of "plus nothing—minus 0.0003 inch." The electric gauge principle was naturally applied to this problem also and with very satisfactory results, $^1/_{10,000}$ inch being expanded to one inch on the scale of the indicating instrument. The refrigerator manufacturer was enabled to inspect his parts more accurately and rapidly than before, and actually to assort his parts for matched assembly within his small tolerance range. Special multiple gauging stands were built, permitting as many as four dimensions to be gauged simultaneously. Points of wear were tipped with tungsten carbide, diamond, or sapphire, and some of the original stands have been in continuous use since 1930 and are still in operation.

The successful operation of these gauges in the plant of the refrigerator manufacturer so impressed a gauge manufacturer that an arrangement was made for supplying the electric gauge to the trade, so that the electric gauge is now well known and is found in many manufacturing plants throughout this country and parts of Europe.

An interesting application of the electric gauge has been made to the tail-stock of the Pratt and Whitney measuring machine enabling this machine to be used for comparison work to a millionth of an inch if proper precaution is taken in regard to constancy of temperature.

Perhaps to the engineer the most interesting and useful application of the electric-gauge circuit is to the measurement of strain. Strain gauges have been built and used with good results in a number of investigations involving the measurement of stress in mechanical and structural members. Studies have been made of stresses in bridge structures during passage of high-speed locomotives, enabling the engineers to study stresses in structures too complex to permit ready calculation, and to investigate the resonant behavior of the bridge as trains crossed it at various speeds. Investigations have been made of stresses in electric locomotive members during service, and of stresses in rails and joint bars under various normal and abnormal conditions. Most of these investigations were carried on with a strain gauge weighing between four and five ounces and having a gauge length of $2^1/_4$ inches. This gauge is sensitive enough to permit measurement of stress as low as 100 pounds per square inch in steel, without the use of amplification.

A recent development in this strain gauge makes use of amplification, not to increase sensitivity but to decrease the size of the gauge head. The result is a gauge head weighing about one-half ounce and having a gauge length of an inch. This small strain gauge is particularly useful for measurement of stresses in aircraft parts and members of small section.

The electric gauge has been applied to cold-strip-steel rolling with surprising results. By the electric gauge the thickness of the finished product is continuously indicated, the pressure exerted on the rolls is measured, and the tension on the strip between stands is both indicated and automatically controlled. These applications of the electric gauge have alone increased the rolling speed from about 250 feet per minute to more than 1,300 feet per minute.

"De-ion" Air Circuit Breakers for A-C Feeder, Motor Starting, and Station Auxiliary Service

By R. C. DICKINSON
ASSOCIATE AIEE

Synopsis: The first circuit interrupters for a-c service were of the air-break type, followed very shortly by oil circuit breakers for general high-voltage service. Air "De-ion" circuit breakers introduced in 1928 provided a new type of circuit interrupter for a-c service. Recent applications of these principles result in a line of De-ion air circuit breakers for 2,500-volt and 5,000-volt ratings suitable for use in a-c feeder circuits, motor starting, and general station auxiliary service.

THE electrical industry used air-type arc-interrupting devices when it first became desirable or necessary to open the circuits between the generators and the loads. Very little was known about arc characteristics except that after an arc was stretched sufficiently, the circuit voltage would not maintain it and the circuit would be interrupted. In about 1895 the increased voltage and power requirements incidental to the extension of a-c systems led to the introduction of the oil circuit breaker on account of its compactness and the confinement of the arc. Both air and oil circuit breakers continued in use for several years, but the advantages of the oil breaker led to the disappearance of the air breaker from the higher voltage a-c fields. The older catalogues indicate the use of air circuit breakers for voltages up to and possibly higher than 66-kv as late as 1902. Figure 1 illustrates this general type of construction as applied to 2,300-volt service.

The oil circuit breaker gradually became the principal factor in high-voltage a-c switching. Nevertheless, the air circuit interrupter has continued for application to d-c service as high as 3,000 volts and for a-c service of 2,300 volts and in some cases at higher voltages. The magnetic blow-out principle was introduced as a modification of the "long arc" principle of circuit interruption and these devices continue in use for moderate power requirements.

The steady growth of the electrical industry resulted in continually increasing concentrations of power and an ever-growing necessity for continuity of service, requiring greater safety and dependability of operation, particularly on the part of the switchgear. Improvements were made in the construction of oil circuit breakers to meet these increasingly severe operating conditions and research was directed into the fundamental principles of a-c circuit interruption.

As a result of this research, the "De-ion" air circuit breaker principle was introduced in 1929[1,2]. This De-ion air-break principle was based on a new concept of arc phenomena resulting from intensive studies of the fundamental structure of matter, which work, of course, had been going on for a good many years.

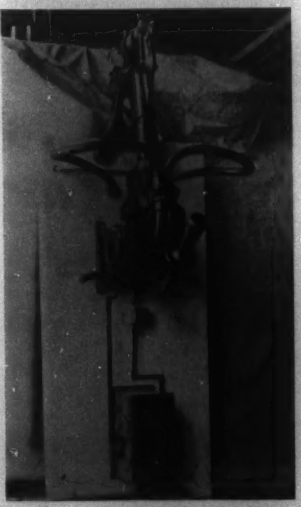

Figure 1. High-voltage 2,500-volt air circuit breaker used as late as 1902 to 1904

Because of the fundamental soundness of the De-ion theory, it then became possible to design circuit breakers for a definite performance. The inherent advantages of De-ion air circuit breakers over other types of air circuit breakers were found to be chiefly compactness, relatively high arc rupturing ability, short duration of arcing, and the control of arc products, and thus opened up new possibilities of switchgear without oil for 25,000 volts and below, and at moderate interrupting capacities.

To review briefly the theory of the De-ion air circuit breaker, its operation depends primarily upon the high initial rate of recovery of dielectric strength of a thin space at an arc cathode, this being in the order of 250 volts within the first microsecond. If a series of N arc spaces is provided, a voltage of 250 N can be interrupted on commercial circuits although a lower voltage per arc space is used in actual practice. Since the interrupting process depends primarily upon the rapid development of a very thin layer of dielectric at the arc cathode, it follows that the individual arcs in the series need not be long and in fact they may be as short as is commercially practicable. The net result is that in a 2,500-volt 100,000-kva De-ion air circuit breaker, capable of interrupting the full 2,500 volts on a single element, the length of the active parts of the interrupter is less than six inches.

In general, the duration of arcing in De-ion air circuit breakers averages from one-half to one cycle at the usual range short-circuit currents. The arc is quickly moved from the arc tips into the interrupting element and the circuit is generally interrupted at the next zero point of current.

The interrupting element of the De-ion air circuit breaker, being composed essentially of a series of copper plates separated by thin insulating spacers, completely encloses the arc and the latter is never exposed to the exterior parts of the breaker. By the proper design and choice of materials it is thus possible to control the expanding gases resulting from the arc. As a result, the De-ion air circuit breaker has been adapted to metal enclosed switchgear which compares favorably in size to corresponding oil switchgear.

The first practical design of a De-ion air circuit breaker was at 2,300 volts. This breaker was not commercialized but several were placed in trial operation on transformer and motor circuits in the East Pittsburgh plant in August 1927.

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1. For all numbered references, see list at end of paper.

Two of these units are still in active service.

The next design of De-ion air circuit breaker was in the 15-kv class, with an interrupting rating of 20,000 amperes, equivalent to 500,000 kva. Approximately 100 of these breakers were placed in central station service between 1928 and 1932, the earliest of these units still being in operation with the original interrupting elements.

Many other interesting applications of the De-ion principle have been made for 5,000-volt, 7,500-volt, 15,000-volt, and 25,000-volt classes. However, this apparatus has in general been more costly to build than corresponding oil breakers and the great increase in oil breaker efficiency in recent years has removed to a large degree the necessity for duplication of apparatus lines.

Since De-ion grids not only became available for new oil circuit breakers, but also were applicable to circuit breakers in the customer's possession, the advantages of the De-ion air circuit breaker became less apparent. However, with the accumulation of field experience with these early De-ion air breakers, certain fields proved logical ones for the exploitation of the De-ion principle:

(*a*) Elimination of fuses from low voltage a-c and d-c switchgear has been very general in recent years and the De-ion principle as incorporated in the small line of breakers illustrated by figures 2 and 3 is typical of the apparatus now serving that field.

(*b*) The 6,600-volt three-phase steel-mill main-motor-drive switchgear has proved a fertile field for De-ion air breakers, because of the fact that these breakers proved their ability to handle highly repetitive service with little or no maintenance. The forward and reverse breakers for main drive motors of 5,000 horsepower at 6,600 volts, are in some cases required to operate 1,500 to 2,000 times per month on starting and full-load currents.

A line of 7.5-kv breakers was introduced in 1933 for this type of service which has since been expanded into metal enclosed equipment of both horizontal draw-out and cubicle construction. Figure 4*a* shows a 1,200-ampere 7.5-kv unit for horizontal draw-out equipment rated at 250,000 kva. This breaker is insulated for the AIEE test for 15-kv breakers. In addition to having the long life inherent in the De-ion construction, this line of breakers is also designed for extra long mechanical life. Some of these units have service records of over 150,000 operations as reported in 1937, and are still in active duty. Approximately 150 breakers of this type have been placed in service. Another form of 7,500-volt De-ion air circuit breaker for lower rupturing capacity is shown in figure 4*b*. In this assembly the complete breaker is mounted within a metal enclosure obtaining a high degree of compactness for this type of equipment.

In view of these developments the question may logically be asked, why cannot the De-ion principle be applied rather widely to the elimination of oil from power house auxiliary switchgear and similar installations? The power requirements are well within the technical limits of the De-ion development and there are certain definite improvements in the switchgear layout which can be made by the elimination of oil.

As a result of the large accumulation of field experience on De-ion air circuit breakers, there has been developed a new line of breakers for ratings up to 100,000 kva at 2.5 kv and 150,000 kva at 5 kv. These are particularly applicable to station auxiliary, motor-starting, and substation distribution-feeder service. In this field of switching equipment, space requirements and economic considerations are predominant factors.

Figure 5 illustrates a 2,000-ampere 3-pole 2.5-kv breaker unit of 100,000 kva interrupting capacity. The general design and construction of this breaker differ considerably from that of high-voltage De-ion air circuit breakers previously described before the Institute.[3] The line terminal bushings are mounted on a vertical steel base plate which forms a foundation for the entire breaker assembly. The interrupting elements or deionizing chambers are mounted vertically over the upper terminal bushings,

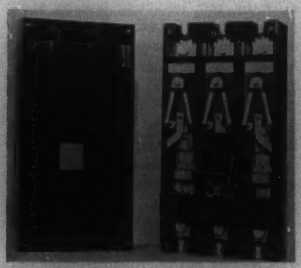


Figure 2. Low-voltage De-ion air circuit breaker, 600 volts alternating current, 250 volts direct current

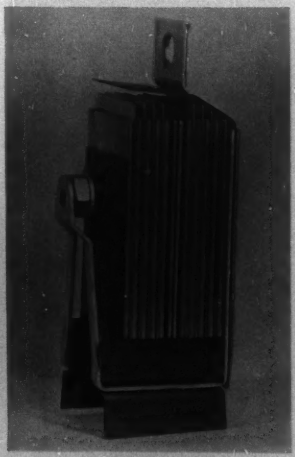


Figure 3. Deionizing chamber for low-voltage De-ion breaker of figure 2

(*a*)

(*b*)

Figure 4. Horizontal draw-out metal-enclosed De-ion air circuit breaker for 1,200 amperes, 7.5 kv, of the type widely applied in 6,600-volt steel mill service

with a small post-type insulator as additional support.

The principles of construction and operation of the deionizing chamber in this new design of breaker are best understood by reference to figure 6. As in breakers previously described before the Institute, the basic principle of initiating the arc at a single contact and then breaking it into a series of short arcs between copper plates is retained. Also as in previous breakers, two magnetic fields are required, one for moving the arc from

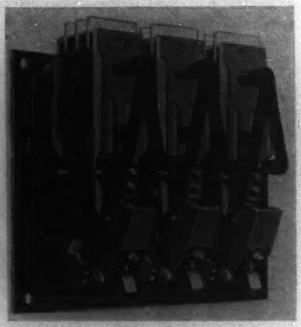
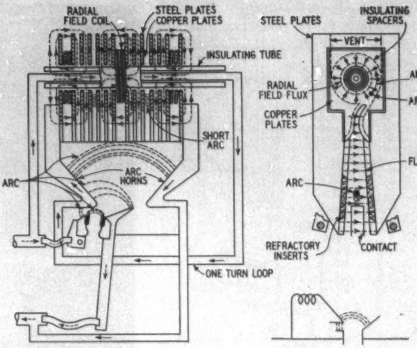


Figure 5. Three-pole De-ion air circuit breaker unit for 2,000 amperes, 2.5-kv, for 100,000-kva interrupting capacity

the arc tips into the series of plates and another, which in reality is a combination of magnetic fields, for rotating the short arcs over circular paths between the plates. These two magnetic fields are generally referred to as the entering or blow-in field and the radial fields. Referring again to figure 6, each copper plate is surrounded on top and sides by a steel plate of the same thickness. These pairs of plates are stacked with thin insulating spacers between, each set of spacers being so shaped as to form pathways for the individual short arcs and arc terminals and also a vent to the top of the chamber for each short arc. At intervals of a few inches in this stack of plates are located coils for supplying the radial magnetic fields. This unit assembly is clamped tightly together by stiff end plates and insulated studs.

In operation, the steel plates, which extend downward below the arc tips, act as a composite magnetic yoke which supplies magnetic flux for moving the arc through the arc box, the space between the arc tips and the lower edges of the copper plates. This yoke is energized magnetically as follows: As the arc is initially formed at the arc tips, the

Figure 6. Illustration of the principles of construction of modern De-ion air circuit breakers showing how the arc is controlled by magnetic fields



flux surrounding the arc current circulates through the steel plates above the arc and across the air gap between the lower ends of the steel plates below the arc. This results in a force reaction to move the arc upward toward the copper plates. The shape of the electrical circuit through the line terminal studs and contact members also assists in the initial upward movement of the arc. The impingement of the arc on the tip of the arc horn energizes the loop circuit, formed by the stud running centrally through the copper plates and returning through the two lower studs in parallel, to the arc horn immediately above the stationary arc tip. The arc horn is insulated from the arc tip sufficiently to withstand the voltage drop caused by the impedance through the loop. This is illustrated in the small diagram in figure 6. As the arc strikes the arc horn, the voltage across that portion of the arc between the contact and horn causes current immediately to flow through the loop. Due to the low impedance of the loop compared to the voltage developed by that portion of the arc in parallel with it, the entire current is quickly transferred to the loop. Since the current in the upper stud flows in the same direction as the arc current this loop then acts as an additional turn for further magnetizing the steel plates. With this strengthening of the entering field, the arc is moved upward into the narrowing throat formed by the tapered slots in the copper plates. As explained previously before the Institute, the purpose of the tapered slot in each copper plate is to increase the voltage of the single arc to effect the transition from a single arc to a multiplicity of short arcs in series.

The radial field coils are electrically connected to adjacent copper plates having extensions below the other copper plates. These coils are introduced into series relationship to the arc current shortly before the arc reaches the ends of the slots in the main copper plates, in a manner similar to that in which the entering field loop circuit was introduced. These radial fields then provide additional impetus for the final transfer of the arc, at the ends of the tapered slots, into the stack of copper plates to form a series of short arcs. Under the influence of the same radial fields, the short arcs then rotate at high velocity in the circular pathways formed by the insulating spacers until the next current zero, when the circuit is interrupted.

In the higher voltage De-ion air circuit breakers, the static shields are provided, along the interrupting element or De-ion stack, in order to divide the voltage evenly among the short arcs. Because of the smaller number of gaps and the greater compactness of the interrupting element of the 2,500- and 5,000-volt circuit breaker, satisfactory distribution of voltage is obtained without the use of external shielding.

The contact system of this breaker is interesting in that springs and full-capacity contact shunts are eliminated without sacrificing the basic advantages of the line-type butt contact. Figure 7 illustrates operation of the contacts. The stationary contacts are fixed on the ends of the two terminal studs, the upper one being a replaceable combination main and arcing contact. The movable contacts are located at the ends of a solid copper bar which forms a bridging member across the stationary contacts, the lower pair of contacts being bridged by a light, flexible shunt. The movable contact member is pivoted at the center through an elongated hole to the actuating lever, with a compression spring between the two. This spring biases the movable contact member against the stationary contacts, in the closed posi-

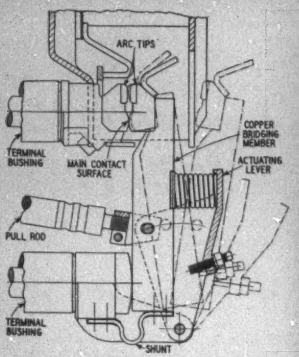


Figure 7. Contact system of the 2.5–5 kv De-ion breaker for station auxiliary and similar applications

tion, and, in opening, gives it a rolling action to cause final separation at the arc tips. These tips are of silver-tungsten, having high resistance against the burning action of the arc.

Solid silver plates in the main contact surfaces maintain low contact resistance over long service periods.

The individual pole units are isolated from each other by insulating barriers of rectangular Micarta tubing. The three-pole breaker is operated by a conventional solenoid mechanism located immediately below the breaker pole units, as shown in the illustration of the test sample, figure 8. Because of its novel arrangement, this breaker is extremely simple and compact and all parts are readily accessible for inspection or maintenance.

An experimental sample 2.5-kv breaker, shown in figure 8, consisting of a single-pole unit mounted on a three-pole frame

Table I. Typical Data From Interrupting Tests on 2.5-Kv De-ion Air Breaker

Test Number	Interrupted Current, Root-Mean-Square Amperes	Restored Voltage, Root-Mean-Square Volts	Time From Energizing of Trip Coil to Arc Extinction (Cycles)
1	220	2,420	7.0
2	323	2,610	6.0
3	1,120	2,060	5.7
4	2,850	2,310	5.7
5	4,160	2,270	5.7
6	7,390	2,200	5.6
7	10,030	2,050	5.3
8	12,000	2,070	5.0
9	14,900	2,290	5.3
10	16,900	2,250	5.2
11	21 100	2,270	5.2
12	20,000	2,200	5.6
13	20,400	2,080	5.5
14	22,200	2,200	5.22
15	25,000	2,510	5.22

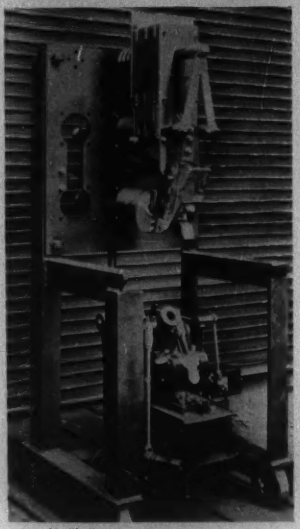


Figure 8. Single-pole experimental model of 2,500-volt De-ion air circuit breaker for 100,000-kva interrupting capacity

and operated by a standard three-inch solenoid, was tested beyond its interrupting rating in the high-power laboratory at East Pittsburgh. Tests were made at from less than 50 amperes to well in excess of 25,000 amperes, the majority of tests being made with from 2,500 volts to 3,200 volts on the test generator with restored voltages from 2,000 to 2,600 volts.

The first continuous series of tests consisted of 144 interruptions, stopping only at intervals to examine the breaker. As many of these tests were repeat interruptions at about the same current levels, oscillographic data from a few representative tests are shown in table I. It will be noted that the time from energizing of the tripping coil to the interruption of the circuit is consistently less than six cycles for currents down to approximately 1,000 amperes, showing a safe operating margin for the standard eight-cycle rating.

All of the above tests were made on the sample breaker as originally built and no part of the breaker was modified or replaced during the tests. These tests represent the equivalent of five years or more interrupting service on the average circuit breaker. Figure 9 shows a deionizing plate taken from the experimental breaker after 45 interruptions, 5 of which were above 20,000 amperes, 17 above 10,000 amperes, 23 above 5,000 amperes, and 44 above 1,000 amperes. This plate shows very little deterioration and was used for subsequent tests. Figure 10*a* shows a typical oscillogram made during an interruption of 25,500 amperes at 2.5 kv. Table II shows typical oscillographic data taken from another series of 19 unit-operation interrupting tests.

The experimental breaker was equipped with a deionizing chamber containing a greater number of plates and insulating spacers, designed for an interrupting rating of 20,000 amperes at 5 kv, equivalent to 150,000 kva. Similar interrupting tests were made on this unit. Table III shows

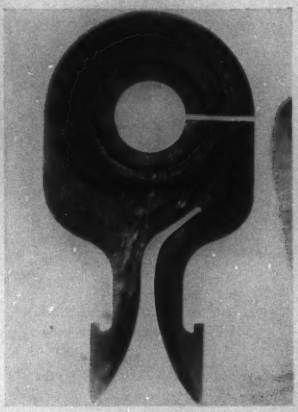


Figure 9. Deionizing plate taken from experimental breaker unit after one series of 45 short-circuit interrupting tests

typical data taken on this series of tests, with breaker interrupting times of less than six cycles. Figure 10*b* shows a typical oscillogram.

In addition to the short-circuit interrupting tests, the suitability of this type of breaker for motor starting, station auxiliary, and other types of highly repetitive service was investigated by three series of endurance runs. The first two runs simulated closing the starting current and opening the full-load current of a 1,000-horse power motor. The test condition was made more severe than service condition by using air-core reactors and thus obtaining a power factor of less than ten per cent. The breaker was closed and opened 7,700 times at 235 amperes, 2,300 volts on the single-pole unit. It was then operated 7,700 times on the CO cycle at 1,350 amperes, 300 volts. This total of 15,400 operations was made without any maintenance

whatever. The deionizing chamber used in these tests had previously been used in 48 interrupting tests, 20 of which were at from 9,000 to 26,000 amperes. The breaker was in good electrical and mechanical operating condition after these tests.

The third series of tests, part of which was included in the first two series, consisted of a mechanical endurance run of 35,000 operations. At the end of these tests, the breaker was still in good overall condition indicating an ample margin for many years of service.

The breaker unit, shown in figure 5, due to its compactness and small space requirements, is suitable for complete metal-clad or cubicle switchgear designs.

Figure 10a. Oscillogram showing typical interruption at 25,500 amperes—2,510 volts restored on single-pole unit

Figure 10b. Oscillogram showing typical interruption at 18,000 amperes, 4,600 volts restored on single-pole unit

Figure 11 shows the preferred horizontal draw-out metal-clad switchgear unit with the De-ion air circuit breaker. Uniformity of design is attained by making this unit adaptable for air breakers of various ratings at 2.5 or 5 kv. The insulation is of the 7.5-kv class. By comparison with the equivalent vertical-lift metal-clad unit equipped with a modern oil circuit breaker of 150,000 kva interrupting capacity shown in figure 12, it is to be noted that the space occupied by the De-ion air

Table II. Typical Data From CO Interrupting Tests on 2.5-Kv De-ion Air Breaker

Test Number	Closed Root-Mean-Square Current (Amperes)	Interrupted Root-Mean-Square Amperes	Restored Root-Mean-Square Kilovolts	Time From Energizing of Trip Coil to Arc Extinction (Cycles)
1	1,080	1,050	2.48	5.4
2	3,500	2,430	2.39	5.5
3	4,700	4,180	2.28	5.3
4	11,300	9,070	2.16	5.7
5	17,400	14,400	2.05	5.7
6	17,500	14,400	2.06	5.8
7	18,000	14,700	2.08	5.8
8	40,000	18,800	1.95	5.6

circuit breaker unit is approximately equal to that for the oil circuit breaker.

In the air breaker unit the high-voltage parts are completely isolated from the low-voltage control circuits by steel barriers. The individual pole units are isolated from each other by rectangular insulating tubes as previously described. Other features of this construction, such as main disconnecting contacts, secondary contacts, insulated bus, etc., follow the most approved construction as applied to modern vertical-lift type metal-clad switchgear with oil breakers. In this

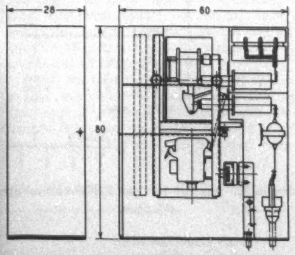


Figure 11. Horizontal draw-out metal-enclosed switchgear unit with De-ion air circuit breaker for 2.5 to 5 kv, 600 to 1,200 amperes, up to 150,000 kva interrupting rating

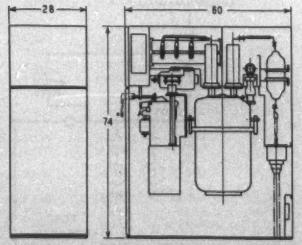


Figure 12. Modern metal-clad switchgear unit equipped with 150,000-kva oil circuit breaker

Table III. Typical Data From Interrupting Tests on Five-Kv De-ion Air Breaker

Test Number	Interrupted Current, Root-Mean-Square Amperes	Restored Voltage, Root-Mean-Square Volts	Time From Energizing of Trip Coil to Arc Extinction (Cycles)
1	1,840	4,610	5.7
2	2,910	4,560	5.8
3	3,660	4,380	5.7
4	6,490	4,300	5.7
5	8,000	4,150	5.60
6	12,900	3,890	5.6
7	13,700	3,860	5.6
8	14,900	3,610	5.7
9	16,000	4,000	5.7
10	18,000	3,600	5.8

unit the De-ion air breaker is horizontally movable to the "disconnect" or test position on rollers near the center of thrust of the disconnecting contacts. From the disconnect position it may be moved out of the cell by means of a small transfer truck, thus permitting convenient removal of the arc interrupting stack for examination and maintenance of the contacts.

Potential transformers are located in superstructures for both types of assemblies and in either case control switches instruments, and relays may be accommodated on panels mounted either on the front or the rear of the unit, depending upon whether the front aisle or both front and rear aisles are available.

Previous designs of De-ion air circuit breakers have found wide spread application in steel-mill, arc-furnace, and other highly repetitive services as well as in power-house feeder applications. It is expected that the completion of these new De-ion circuit breakers for lower voltage applications will extend the advantages of this type of construction to power-station auxiliary service, general motor-starting service, and substation-feeder applications.

References

1. Extinction of an A-C Arc, J. Slepian. AIEE Transactions, volume 48, April 1929.

2. Theory of the De-ion Circuit Breaker, J. Slepian. AIEE Transactions, volume 48, April 1929.

3. Structural Development of the De-ion Circuit Breaker, R. C. Dickinson and B. P. Baker. AIEE Transactions, volume 48, April 1929.

Discussion

J. A. Adams (Philadelphia Electric Company, Philadelphia, Pa.). It is particularly gratifying to see continued development of the De-ion air circuit breaker in capacities which can be used extensively in distribution

substations. The Philadelphia Electric Company installed two De-ion breakers experimentally in 13.2-kv service in 1931, and in 1934 installed eight more on 4-kv circuits. These have operated successfully under both normal and short-circuit conditions. As a result of this experience it is planned to install three additional breakers in 13.2-kv service, two in 4-kv service, and three in 4.8-kv service this year.

While there may have been a great increase in oil circuit breaker efficiency during the last few years, as pointed out in this paper, it would seem that the nonoil-type breaker has a field of its own regardless of this development. This is implied in the paper by the statement that "there are certain definite improvements in the switchgear layout which can be made by the elimination of oil." A type of installation where it would be particularly advantageous to use nonoil-type breakers appears to be the unattended substations. The authors ask, "Why cannot the De-ion principle be applied rather widely to the elimination of oil from power house auxiliary switchgear and similar installations?" It is not clear why the same line of reasoning should not be extended to the main indoor switchgear. It would seem that a logical development for the nonoil-type breaker is in the higher current carrying and higher interrupting capacity ratings.

Philip Sporn (American Gas and Electric Service Corporation, New York, N. Y.): Mr. Dickinson's paper, describing the 2,500-volt and 5,000-volt "De-ion" circuit breaker development is another indication of the increasing work on the design and the increasing interest in the use of air-type breakers for certain applications, particularly for station auxiliary service. From the description of the design and tests as given in this paper, it appears that an air circuit breaker with very good characteristics and performance has been produced.

I believe that it would be of interest to present here a brief description of a development along the same lines which was made in connection with the recently completed extension to our Logan, W. Va., plant. When this high-pressure extension to the plant was planned, the engineering and design having been started in 1935, it was felt that because of crowded conditions it would be a decided advantage in the auxiliary service for all of the new portion of the plant to use circuit breakers without oil. Such development had been under discussion for several years with the engineers of the ITE Company. Accordingly, the development of a suitable 2,300-volt air circuit breaker, having a rupturing capacity of 125,000 kva, was launched. The development was completed with the carrying through of a series of tests made at the Logan plant in April of this year.

As compared with the De-ion type of air circuit breaker described by the author, this breaker, developed by the ITE Company, is fundamentally of the magnetic blow-out type, using a special type of arc chute designed for rapid cooling of the arc.

The tests on one of these breakers at the Logan plant demonstrated very satisfactory performance. I shall attempt to describe these tests briefly with the aid of a few illustrations.

Figure 1 shows one of the 2,300-volt 1,200-ampere air circuit breakers set up in the yard at the Logan plant for the short-circuit tests. With the capacity that could be made available at the plant without interfering with the plant operation, it was not possible to obtain the full breaker rating of 125,000 kva, but by means of a special connection in which a 6,000-kva auxiliary bank was reversed from its normal direction of transformation, we were able to obtain more than 100,000 kva. The normal method of connecting this bank is shown in figure 2 from which you will note that the three 5,000-kva generators are operated at 4,000 volts in parallel with one of the windings of the large 100,000-kva bank, and with the 6,000-kva bank stepping down from 4,000 volts to 2,300. As this set-up gave a calculated short circuit of around 60,000 kva or only half of the rating of the breaker, it was decided to change the connection to that shown in figure 3 in which the three 5,000-kva generators were connected in parallel with the 2,300-volt side of bank 15 instead of the 4,000-volt bus. Although the generators operated at reduced excitation, this set-up provided a much greater short-circuit current than could be obtained in any other manner at 2,300 volts.

Altogether 25 shots were made on this breaker, with short-circuit current varying from approximately 3,000 amperes to a maximum of 22,800 amperes, and with voltages from 2,300 to above 4,000 volts. While time is not available to describe these tests in detail, a fairly complete record of the tests is shown in table I. You will note that, with the set-up in which the three 5,000-kva generators were connected in parallel with the 6,000-kva bank, a maximum recorded total root-mean-square current of 22,800 amperes was obtained on test 14. In order to overcome as far as

Figure 1. ITE 2,300-volt air circuit breaker set up for tests at Logan

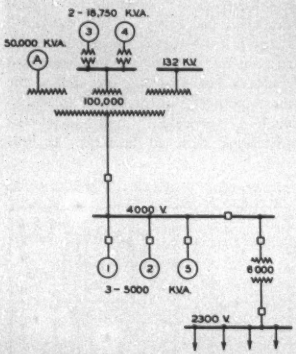


Figure 2. Normal 4-kv and 2,300-volt set-up at Logan

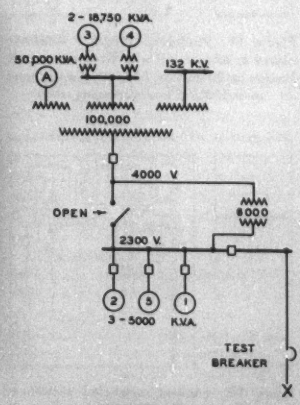


Figure 3. Special connections for 2,300-volt tests at Logan

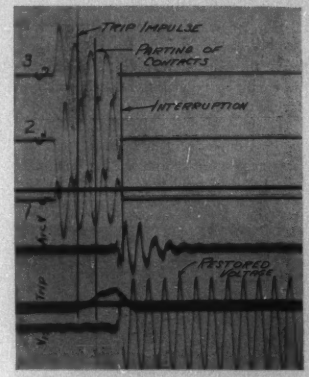


Figure 4. Oscillogram of test number 14 interrupting 22,800 amperes at 2,300 volts in three cycles

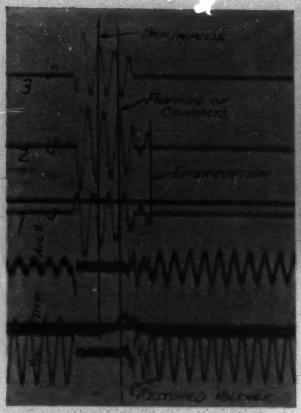


Figure 5. Oscillogram of test number 23 interrupting 15,200 amperes at 4,500 volts in 3.75 cycles

Figure 6. Contacts of ITE 2,300-volt air circuit breaker after short-circuit tests

Figure 7. ITE 2,300-volt air circuit breaker with one arc chute removed

possible the effect of reduced excitation on the value of short-circuit current, the three generators operating in parallel with the system through the 6,000 bank were loaded with reactive kilovolt-amperes up to more than half of their respective ratings by increasing the field excitation.

You will also note from table I that the circuit breaker time, that is, the time in cycles measured from the trip impulse to the actual interruption of the arc, averaged approximately four cycles or less, throughout, with the exception of a single test of 6¾ cycles in the third group. The extra long time in this case was undoubtedly due to an *overloaded trip mechanism*. On test number 10 immediately preceding this shot, the breaker failed to trip, entirely from this cause; while on the next shot, which was taken without making any adjustments, tripping occurred but was considerably delayed, as shown by the longer time on the oscillogram. At this point in the program the tripping mechanism was adjusted to relieve the excessive strain and, thereafter, normal tripping time was obtained throughout the remainder of the tests.

Having shown that the breaker gave satisfactory performance with the highest current that could be obtained at 2,300 volts, it was decided to test the breaker, using the three generators alone excited to 4,000 volts or above. The last two groups of tests from number 17 to number 23, inclusive, in table I represent these tests made at the higher voltage. The last two tests made at 4,300 volts gave a maximum total root-mean-square current of 16,000 amperes. It will be noted that the breaker time for all of the tests at the higher voltage was less than four cycles.

In all the tests at heavier current values, a flash was observed above the breaker at the time of interruption. That this was mainly light and not actual fire was fairly well demonstrated by a ball of cotton which was suspended above one of the arc chutes and which was not ignited until the final shot made at 4,300 volts.

Figures 4 and 5 show typical oscillograms taken during these tests. Figure 4 represents test number 14 on which a current of 22,800 amperes at 2,300 volts was interrupted in three cycles. Figure 5 shows test number 23 on which a current of 15,200 amperes was interrupted in 3.75 cycles.

Twice during the tests the arc chutes were removed and contacts examined. Each time, a moderate amount of dressing of the main contacts was done before proceeding with additional tests, but the arcing con-

Table I. Short Circuit Tests at Logan on ITE 2,300-Volt Air Circuit Breaker

Test Number	Type	Generators	Bank No. 15 6,000 Kva	Volts	Initial Current in Arc			Breaker Time (Cycles)			Equivalent Kilovolt-amperes Interrupted
					1	2	3	1	2	3	
1	O	1	Open	2,300	2,850	3,080	3,130	4.0	4.0	4.25	12,500
2	CO	1	Open	2,300	3,340	3,910	3,180	3.25	3.25	3.25	15,500
3	O	2	Open	2,300	4,300	4,910	5,080	4.0	4.0	4.25	20,000
4	CO	2	Open	2,300	6,450	1,750	5,150	2.75	2.75	2.75	28,500
5	O	None	Closed	2,390	12,400	13,300	13,500	3.75	4.0	4.0	56,000
6	O	None	Closed					No Record			
7	CO	None	Closed	2,390	9,650	12,300	11,800	2.75	2.25	2.25	51,000
8	CO	None	Closed	2,390	12,300	12,500	12,900	2.75	2.75	2.75	53,000
9	O	2	Closed	2,430	15,600	17,000	18,000	4.0	4.0	4.0	75,000
9A	O	2	Closed	2,470	18,200	15,200	12,900	4.0	3.75	3.75	75,000
10	O	2	Closed					No Record			
10A	O	2	Closed	2,430	13,500	16,500	16,800	6.25	6.75	6.25	70,000
11	CO	2	Closed					No Record			
12	CO	2	Closed	2,470	13,900	14,500	16,800	2.25	2.25	2.0	70,000
13	O	3	Closed	2,570	20,900	19,200	17,400	3.0	3.0	3.0	93,000
14	O	3	Closed	2,560	17,700	22,800	16,300	3.0	3.0	2.75	101,000
15	CO	3	Closed					No Record			
16	CO	3	Closed	2,640	16,100	23,300	17,400	2.25	2.25	2.25	99,000
17	CO	1	Open	4,000	5,900	5,920	5,460	2.75	2.75	2.75	41,000
18	O	2	Open	4,000	9,650	7,600	6,500	3.5	3.5	3.5	67,000
19	CO	2	Open	4,000	5,360	9,400	8,000	2.25	2.25	2.25	65,000
20	O	3	Open	4,000	12,850	12,200	7,850	3.25	3.25	3.25	89,000
21	CO	3	Open	4,000	10,200	13,400	10,100	2.0	2.0	2.25	93,000
22	O	3	Open	4,300	16,100	13,900	9,500	3.75	3.75	3.75	111,000
23	CO	3	Open	4,300	14,100	15,200	13,500	3.25	3.75	2.25	105,000

tacts were not touched, and the amount of burning on these contacts was considered very small. The appearance of these contacts after the heavy current shots and prior to dressing is shown in figure 6.

Figures 7 and 8 are included to give a better idea of the appearance of this breaker. Figure 7 shows the breaker with one arc chute removed, while figure 8 shows a group of these breakers as they would appear assembled for service.

Figure 8. Assembled group of ITE 2,300-volt air circuit breakers

J. R. North (The Commonwealth and Southern Corporation, Jackson, Mich.): Keen interest is being shown throughout the industry in low-voltage indoor oilless circuit breakers, particularly for station auxiliary service at 2,400 volts in large generating stations. The "De-ion" air circuit breakers described by Mr. Dickinson would seem to have considerable possibility for such applications and should be very easy to inspect and maintain.

However, for properly evaluating these air circuit breakers, we should like to inquire regarding some of the design features.

(a) What are the ventilation requirements from the standpoint of temperature rise and also from the standpoint of flame emission.

(b) What is the duty cycle upon which the interrupting capacity ratings are based and what, if any, de-rating factors need to be applied for various reclosing duty cycles.

(c) What is the insulation strength—60-cycle flashover, impulse flashover minimum clearance to ground, and striking distance.

(d) What is the five-second current-carrying rating of these breakers (root-mean-square amperes), as compared with their interrupting current rating.

M. H. Hobbs (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The series of tests given in Mr. Dickinson's paper, particularly those showing repetitive duty, show that we now have a circuit breaker which is apparently the answer to the requirements for severe service on motor and feeder circuits for station auxiliaries. A number of these have already been manufactured for this application, extending to other types of duty the operating advantages of "De-ion" breakers, which have proved so outstanding on heavy steel mill locations during the past several years.

Mr. Dickinson mentioned that the De-ion breaker is readily adaptable for mounting in metal-clad switchgear assemblies. This fact is more important now than ever before as the large majority of indoor switchgear is now this type, not only for station auxiliaries but for other general applications. It is equally important that all of the advantages of the designs of metal-clad switchgear for oil circuit breakers acquired during the years of its development should be retained in the structure for the De-ion breaker. Figures 11 and 12 show the two comparative structures, for oil and De-ion breakers respectively, and indicate comparative dimensions. It will be noted that the De-ion breaker is arranged as a horizontal draw-out unit as contrasted with the vertical draw-out arrangement for the oil breaker. This works out more satisfactorily for the circuit breaker design on account of the horizontal position of the arcing chamber and presents no handicaps as far as the switchgear is concerned. It would be just as illogical to use the vertical arrangement for this breaker as it was to use the horizontol for oil breakers having vertical stubs.

As noted from the two figures, the width and depth dimensions are identical, and the height of the De-ion unit is six inches more than the corresponding oil breaker unit. It would be possible to reduce the height except for the fact that space must be provided in the rear for potheads or similar cable terminating facilities. Accommodations for instrument panels are equivalent in that they can be mounted either in the front or rear, depending upon space facilities, that is whether only a single aisle or aisles front and rear are available.

Of course, no provision is necessary for circuit breaker gas exhaust as in the case of the oil breaker unit, although a small amount of ventilation is incorporated to assist in the small amount of gas dissipation which does occur. Porcelain is used for supporting the primary contacts, and completely insulated connections and busses are used in the housing. It is desirable to provide complete isolation of the secondary wiring from the primary compartment, and this is also provided for. Provision is made for automatic secondary contacts and for operation of the circuit breaker in the test position by means of a jumper. The usual interlocks insure that contact will not be broken on the disconnecting devices unless the circuit breaker is in the open position.

The availability of this breaker therefore enables us to have a complete switchgear unit, including bus, disconnecting devices, and instrument transformers, without the use of oil or compound in any of the compartments.

R. C. Dickinson: It is very pleasing to hear of the favor with which the 15-kv and 5-kv "De-ion" air breakers are regarded by the Philadelphia Electric Company as reported by Mr. Adams. This is typical of the high type of performance given by these breakers.

As Mr. Adams says, the non-oil type breaker has a field of its own regardless of the present state of oil breaker development. As pointed out in this paper, the widest field for the De-ion breaker, in general, has been where more frequent operation, either on overload or switching, is involved. The absence of oil deterioration and the long life of the contacts and interrupting element make this type of application most logical. However, since the De-ion air breakers are generally equipped with standard operating solenoids and interrupt the complete range of currents within their rating, they are suitable for any application where oil breakers might be applied.

In answer to a question raised by Mr. North, the De-ion air breaker is rated on the basis of the standard AIEE interrupting duty cycle and equivalent oil breaker de-rating factors are used for various reclosing duty-cycles. The De-ion breaker may be expected to require considerably less maintenance for the same duty than the ordinary oil circuit breaker.

In regard to continuous ratings, these breakers are at present supplied up to 2,000 amperes, and higher ratings will be built as occasion demands. As to higher interrupting ratings, the present ratings do not parallel oil breaker ratings in the higher kilovolt-ampere brackets. It is to be hoped that development efforts will eventually result in ratings equivalent to the higher capacity oil circuit breakers.

As to ventilation requirements, as Mr. Hobbs states in his discussion, a small amount is desirable for the dissipation of such gas as may be incident to circuit interruption but it is also desirable to assist in cooling the current carrying parts and reduce the possibility of moisture condensation on solid insulation surfaces. A small opening at the bottom of the cell door and one or two openings at the top of the cell are sufficient. The upper openings may be made drip-proof. There is no appreciable pressure built up within the cell and the gases are dissipated quite readily. Since the arc is ruptured in a completely enclosed chute, it will be obvious that no large amount of gas is set free in the cell as would be the case in an open magnetic chute construction. Years of service have indicated that the gases expelled from the breaker have caused no interference with operation nor undue maintenance. In fact, the maintenance on these breakers has been reported as unusually low.

We appreciate keenly Mr. Sporn's remarks and his interest in air circuit breakers. The new De-ion air circuit breaker has performed well on tests and over ten years of field experience on larger breakers of higher kilovolt-ampere rating, on which numerous field tests were made, indicates that these breakers will perform well in service. It is to be noted that single-phase interrupting tests were referred to in the paper. We value these tests quite highly since in most instances the actual restored voltage on the single-pole unit was as much or greater than the line-to-line

Enclosed Low-Voltage "De-ion" Air Circuit Breaker of High Interrupting Capacity

By JEROME SANDIN
ASSOCIATE AIEE

Synopsis: The demand for protection against fault currents up to 20,000 amperes at 250 volts d-c or 600 volts a-c has led to the development of air circuit breakers having the desirable features of the present line of enclosed air circuit breakers, but having higher interrupting capacity. Tests at 20,000 amperes on the circuit breaker of lower interrupting capacity showed that certain modifications were necessary. By increasing the gap between the contacts, by using contacts which resist welding, and by using a modified arc chamber and contact construction, it was found possible to make the breaker satisfactory for 20,000-ampere short circuits.

Introduction

AN INTERESTING type of enclosed "De-ion" circuit breaker was developed some years ago to meet the demands of industry for a protective device with desirable characteristics such as:

1. Small size to permit the construction of safe, compact, and efficient panel boards, switchboard, and separate enclosures.
2. Sufficient capacity to be operated repeatedly without delay in a satisfactory manner under any condition to which it may be normally subjected.
3. Time delay to permit temporary overloads and instantaneous trip to remove short circuits instantly.
4. Sufficient interrupting capacity.
5. Safe to operate and free from fire hazard.
6. Nontamperable.
7. Easy to install and operate.
8. Low in cost.

This type of circuit breaker is made in frame sizes ranging from 50 to 600 amperes at voltages up to 250 volts d-c and 600 volts a-c and has a rupturing capacity of 10,000 amperes. This construction includes a molded insulated housing, De-ion arc chambers, an operating mechanism, a removable automatic trip unit, an insulated operating handle, and end terminals.

At the time these breakers were developed, 10,000-ampere interrupting capacity was considered ample to handle almost all of the industrial lighting and power circuits of 250 volts d-c or 600 volts a-c. Since then, however, industry has been using increasingly larger blocks of electrical energy, thus making it more and more necessary to have similar compact circuit breakers to handle short circuits of greater capacity. In order to meet this demand, the largest of these available breakers, namely the 600-ampere frame size was chosen for test and modification. A short-circuit interrupting capacity of 20,000 amperes at both 250 volts d-c and 600 volts a-c was set as the goal for this development.

The circuit breaker of higher interrupting capacity is intended for installation in switchboards or separate steel boxes, and for the protection of lighting and power circuits of large buildings or industrial plants where fault currents up to 20,000 amperes must be opened.

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JEROME SANDIN is associated with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Acknowledgment is made to Mr. L. R. Ludwig, Mr. G. G. Grissinger, and Mr. B. P. Baker for their valuable contributions to this development. Much credit should go to Mr. B. P. Baker for carrying out the initial part of the development, and to Mr. L. R. Ludwig for his very material assistance in the preparation of the paper.

The original small size of the breaker was retained during the development. This was important since the size of the switchboards or the building space that must be set aside for them need not be increased. Further, most of the details of the breakers of the 10,000- and 20,000-ampere interrupting capacity are interchangeable which from a manufacturing and cost standpoint is very desirable.

Limitations of the Original Circuit Breaker

The 600-ampere circuit breaker of 10,000-ampere capacity is provided with silver main and secondary contacts, silver-tungsten (30 and 70 per cent proportion) arc contacts and arc chambers of the radial field type which is described in detail under the subtitle "Arc Chambers." Externally, both the original breaker and the finally developed breaker of high interrupting capacity, are alike. Figure 1 illustrates either of them. Figure 2 is typical of this type of breaker construction.

Figure 1. Two- or three-pole, 600-ampere circuit breaker of either 10,000- or 20,000-ampere interrupting capacity

Tests on the original circuit breaker at

voltage rating of the three-pole breaker. On many tests the generator was excited to more than 3,000 volts open circuit, single phase, on the 2,500-volt breaker and to 6,000 volts on the 5,000-volt breaker.

Replying to Mr. North's questions regarding insulation and current-carrying capacity without getting into the commercial ratings of these breakers, we can merely state that this class of breakers for 2,500- and 5,000-volt service are insulated to meet the AIEE requirements for 7,500-volt service and their short time ratings are compatible with their interrupting ratings at rated voltage.

In closing, I wish to thank all those who have entered into this discussion for their interest and favorable remarks.

20,000 amperes showed three limitations namely:

1. The arc frequently re-established between the moving and stationary contacts after it had traveled into the arc chamber away from the contacts, indicating that the distance between the contacts was too small.

2. The silver main contacts of both stationary and moving members welded together occasionally when short circuited with the breaker initially closed, but they welded almost always when the breaker was closed on the short circuits.

3. The arc chambers were of insufficient size to effectively vent and deionize the increased volume of ionized gas.

Theories, Modifications, and Improvements

Contact Separation

A greater gap between the contacts in the open position is required on higher short-circuit currents because of the presence of a greater amount of ionized gas between the contacts when 20,000 amperes is being interrupted.

Increased distance between the arc contacts allows the use of a larger number

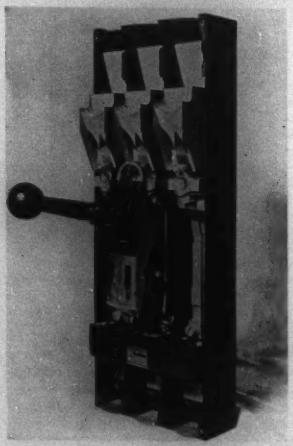


Figure 2. Three-pole, 600-ampere circuit breaker with cover removed, of 20,000-ampere interrupting capacity. Final construction

of plates in the arc chamber, increases the resistance of the arc, increases the discharge of ions to the plates if a larger number are used, and increases the neutralization of the ions by recombination, all of which facilitates the deionization of the gas.

The separation between the arc contacts was increased from $^{13}/_{16}$ inch to $1\ ^{1}/_{8}$ inches, or about 40 per cent. Tests up to about 36,000 amperes proved that this spacing was adequate.

Contacts

Silver contacts are very acceptable for current-carrying purposes since they show only a relatively small increase in contact drop after continuous duty. However, they weld together easily when subjected to high currents because of either high contact drop caused by the lessening of the contact pressure by magnetic forces, or by premature parting of the contacts before the mechanism is released by the trip unit and latch. To offset the effect of these magnetic forces it is necessary to increase the contact pressure by mechanical means or to provide a curved flexible conductor which will exert magnetic forces in such a direction as to cause increased contact pressure with increased current. If welding cannot be wholly eliminated in these ways, it is necessary to use another contact metal which is more resistant to welding.

The first modifications to the breaker included greater contact pressure and a change of the contacts from silver against silver to silver against silver-tungsten of 60 and 40 per cent proportion, to prevent the welding together of the contacts. This combination was tested at 20,000 amperes. The main contacts did not weld together when the short circuits were thrown on the breaker in the closed position, but welding occurred in about half of the tests when the breaker was closed on the short circuits.

Silver tungsten normally increases the contact drop but this was partially offset by increasing the contact pressure. The contact drop remained approximately the same for the first four short circuits and then began increasing rapidly due to the burning of the contact material.

A change in the main contacts from silver against silver-tungsten to silver-tungsten against silver-tungsten of 60 and 40 per cent proportion was tried. This combination did not entirely eliminate the possibility of welding when the breaker was closed on 20,000-ampere short circuits but the percentage was reduced.

Main contacts made of silver-molybdenum were tried in order to overcome the contact welding problem. The tests were highly satisfactory from this standpoint, for at no time did these contacts weld together on short circuit. The contact drop remained approximately the same throughout the tests. These contacts also showed considerably less signs of burning away than did the silver-tungsten contacts. However, silver-molybdenum contacts were found to have a very decided drawback. The drop across these contacts increased appreciably in a few days due to the oxidation of the molybdenum. A number of breakers without current were exposed to an ordinary atmosphere from one to three weeks, and they were tested for contact drop from time to time. Some of these breakers were in closed position and others were in open position. The drop readings across these breakers were initially between 12 and 18 millivolts at 250 amperes d-c, and the final drop values varied

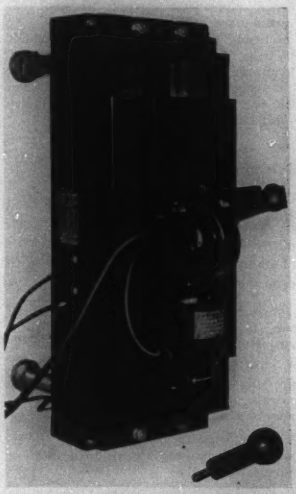


Figure 3. Two- or three-pole, 600-ampere circuit breaker of either 10,000- or 20,000-ampere interrupting capacity with motor mechanism for electrical operation

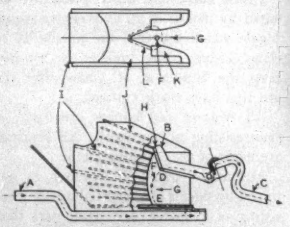
anywhere from 30 to 150 millivolts depending on the length of exposure. A breaker having a drop of about 50 millivolts was tested with full-load current for about 48 hours continuously, but strangely there was no increase in contact drop during this time. It was decided to abandon the use of silver-molybdenum because of the appreciable increase in contact loss under ordinary atmospheric conditions.

A contact construction was finally produced which included the following changes:

1. Silver-tungsten contacts of 30 and 70 per

cent proportion for all moving and stationary members to positively prevent welding at 20,000 amperes or more, with either close-open or open-close-open breaker operation. The use of this alloy reduces the burning of the contact material to a minimum.

2. Center contact members of the roll type which make contact at the heel or farthest point from the arc chamber when the breaker is closed and which roll to the toe or into the slot of the arc chamber while the breaker is opening. This center contact takes the place of the secondary and arc contacts of the old construction which derived their



A—STATIONARY CONTACT MEMBER
B—MOVING CONTACT MEMBER
C—FLEXIBLE CONDUCTOR
D,E,AND F—FLUX AT D AND E TEND TO FORCE ARC F IN DIRECTION G
H—ARC HORN FACED WITH SILVER-TUNGSTEN TO REDUCE BURNING
J—STEEL PLATES
K—ARC SHIELDS
F,G,AND L—FLUX L PULLS ARC F IN DIRECTION G

Figure 4. Schematic diagram of stationary and moving arc contacts and arc chamber

pressure from one spring. All of this spring pressure is now used for the one center contact thus giving less contact drop.

3. An arcing horn at the end of the center moving contact, to elongate the arc and to more positively insure that the arc strikes all of the plates in the arc chamber. Facing the arcing horn with silver-tungsten (30 and 70 per cent) reduced the burning of the horn considerably and thereby lessened the amount of gas.

4. Moving and stationary contact members, consisting of two outside main contacts and one center arc contact, having a definite contact opening and closing sequence to reduce the burning of the contact material and to positively insure the formation of the arc between the arc contacts and not between the main contacts. This contact sequence consists of the right-hand main contact parting ahead of the left-hand main contact which is followed by the parting of the arc contacts. Since the drop is approximately the same across each of these contacts, the resistance does not rise too rapidly when the contacts are parting.

5. The direction of the flow of current through the stationary conductor to the center contact was changed to assist forcing the arc into the arc chamber. The change in current direction produces a flux condition which exerts a force on the arc in the proper direction, as shown in figure 4. The old construction produced flux, which tended to force the arc at one end away from the arc chamber.

Short-circuit tests on breakers having these modifications show that contact welding has been entirely eliminated, that contact burning has been considerably

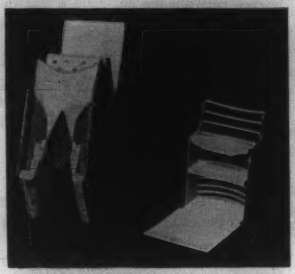


Figure 5. Arc chamber of 20,000-ampere interrupting capacity

reduced, that there is less outward disturbance, and that the rupturing capacity of the breaker has been considerably increased.

Arc Chamber

The arc chamber used during the early stages of this development is of the cold-cathode type which has a radial field for the purpose of spinning the arc to keep the electrodes cool.

This arc chamber consists essentially of a series of copper plates, each fitted into and surrounded by a steel plate except for a V-shaped opening through which the arc contacts move. These plate assemblies are stacked one upon the other and insulated from each other by fiber. A flat coil is located at the center of the stack of plates and is connected to the two adjacent copper plates so that it is in series with the line after the arc is broken into a series of small arcs between the copper plates. The flat coil has a center steel core and produces a radial field from the core to the surrounding steel plates.

In addition there is a one-turn coil which is connected to the stationary arc contact and to the line terminal so that the arc contacts and the coil are in series when the main contacts part. This coil energizes the iron surrounding the copper plates and causes the arc to be moved from its point of inception up into the narrow part of the V plates. From this point the arcs are under the influence of the radial field and are moved with a high velocity in an annular path formed by the insulation between the copper plates.

When alternating current is being interrupted, these series arcs continue to rotate until the current reaches its natural zero value. The d-c arc is extinguished as soon as the current is reduced to zero, which depends on the inductance of the circuit and the amount the arc voltage exceeds the line voltage.

The arc chamber as described above was enlarged by increasing the number of copper plates from nine to 12 in order to take care of the heavier short-circuit currents. These additional plates increase the plate area which helps to cool the hot gases and assist the process of deionization. Since the spacing between the plates remains unchanged, the additional plates will permit increased venting which will help to increase the interrupting capacity.

The enlarged arc chamber was short-circuited at 20,000 amperes on both 250 volts d-c and 600 volts a-c. It interrupted all of the short circuits it was subjected to.

It was thought that by use of the plain-plate type of arc chamber, as shown by figure 5, the following advantages could be obtained at the higher short-circuit value.

1. Better insulation between the line and load sides of the breaker in open position because of the elimination of the shunt which connects the top plate of the arc chamber of the radial field type to the load side of the breaker.
2. Increased venting of the arc gases.
3. Simpler construction.
4. Better performance on direct current.

The arc chamber of this plain-plate type consists of a series of V-slotted steel plates mounted between insulated supports, and it is so placed that the slots of the steel plates extend over the arc contacts. The moving arc contact must pass through the slotted steel plates as it leaves the stationary arc contact. As this action takes place, the arc formed is magnetically driven into the steel plates and is usually broken into a series of short arcs, depending on the amount of current and whether the current is alternating or direct.

The tests on the plain-plate type of arc chamber indicated increased venting, resulting in less back pressure and less burning of the contacts, better insulation between the line and load side of the breaker, more satisfactory performance on direct current, and less heating of the arc chamber which permits less interval of time between short circuits. As a result of these tests, the plain-plate type of arc chamber was adopted for the heavy-duty breakers.

Tests on this arc chamber also indicated that an arc produced by small a-c short-circuit currents usually does not transfer to the steel plates and form short series arcs, but an arc produced by heavier a-c short-circuit currents or not too low d-c currents usually would transfer to the steel plates and form the short series arcs. The degree of venting at the top end of the steel plates determines largely

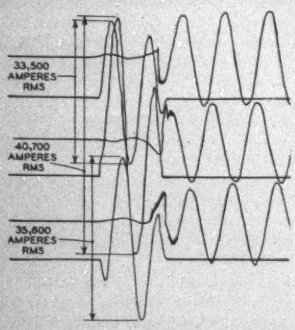


Figure 6. Oscillogram showing a three-phase interruption at 36,000 amperes, 600 volts, 60 cycles

whether or not the arc transfers to the steel plates. Free venting encourages arc transfer.

Deionization of the arc is effected either by the ions neutralizing their charges among themselves or by discharging into the electrodes. The current and voltage a given device can interrupt depends on the length of the arc, the material and size of the electrodes, the proximity of the walls or plates to the arc, the degree of venting, and number of series arcs which determine the number of positive-ion-spaced-charge sheaths in front of the cathode. Those who wish to learn of the fundamentals of arc phenomena should refer to previous articles[2-5] which treat this subject very thoroughly.

When alternating current is being interrupted, the arc or the series arcs continue until the current reaches its natural zero value. At this time the processes of deionization transform the conducting ionized gas into an insulating gas. This prevents the arc from re-establishing by preventing the line voltage from building up current in the opposite direction. The a-c arc is extinguished at the end of the first half cycle.

The arc motion is the same for alternating and direct current, although the effect on the circuit and the way the arc is extinguished is quite different. For a given line voltage a much larger number of plates and much larger gap between the arc contacts must be used for direct current so that the total arc voltage is greater than the line voltage. This difference between the arc voltage and the line voltage is necessary to cause the current to decrease to zero.

Arc shields line both sides of the arc chamber to prevent the arc from burning or striking the lower sides of the steel plates. The burning of unprotected sides of steel plates tends to cause an excess of gas. The striking of the unprotected sides by the arc occurs mainly on low d-c currents, and hinders the arc from rising to the end of the slot, thus causing prolonged arcing.

The arc splitters are spaced to form three compartments directly above the steel plates of each arc chamber to prevent reignition of the arc gas as it is vented from the plates.

Table I. Contact-Drop Data Taken After Short-Circuit Tests

Amperes at 600 Volts, 60 Cycles, 3 Phase	Test Cycles	Millivolts Drop at 250 Amperes D-C		
		Left Pole	Center Pole	Right Pole
.....	.....	*7.4	*7.8	*6.8
20,000	O			
20,000	CO	6.5	5.5	5.4
20,000	O			
20,000	CO	7.5	7.2	6.5
20,000	O			
20,000	CO	6.2	6.6	7.1
32,000	O			
32,000	CO	18.2	9.8	13.5

* Initial drop readings

The arc formed between the arc contacts is acted upon by two forces, which tend to draw it away from the contacts into the steel plates of the arc chamber as shown by figure 4. They are namely: the flux at *D* and *E* which is created by the direction of flow of the current through the arc contacts, and the magnetic field produced in the steel plates.

Description of the Final Developed Circuit Breaker

The circuit breaker is built in an enclosed insulating housing of two parts known as the base and cover. The parts are made from "Moldarta" of a composition selected to give proper mechanical strength, resistance to such heat as it may be subjected, and to resist warping and the absorption of moisture. Both base and cover are provided with deep ribs or walls to permit close assembly of the different poles and to give adequate strength.

An operating handle made of Moldarta is provided to close, open, and reset the breakers. This handle moves in a shielded slot located near the center of the cover. Position indication is obtained from the operating handle. Upper position of the handle indicates the breaker is closed, lower position of the handle indicates the breaker is opened, and mid-position of the handle indicates automatic tripping.

Quick make and quick break are assured by means of an over-center spring toggle which prevents the possibility of slow closing. The breaker is trip-free from the handle at all times after the arc tips have made contact.

All triggers and latches are made of rust-resisting nitride steel. All bearings are made of noncorrosive metal.

Automatic overload tripping is obtained by means of a thermal release consisting of a heater, a bimetal part that changes its shape with change of temperature, and a trigger which is moved by the bimetal part to unlatch the breaker. Resulting time limits are sufficient to prevent interruptions due to overloads of short duration and still give full protection against heating.

Supplementing the thermal release, there is a one-turn electromagnet which trips the breaker instantaneously on currents ranging from six to eight times the normal current rating.

Both the thermal and magnetic releases are mounted on a base, together with a trip bar and trigger. This unit is called a trip unit and is made up in different current ratings. These trip units can be easily removed from the breaker, and are interchangeable which permits a change in current rating to be made after installation.

Figure 2 shows a final developed circuit breaker with the cover removed. Figure 3 shows a complete circuit breaker of either 10,000- or 20,000-ampere interrupting capacity with a motor mechanism for electrical operation.

The circuit breakers are rated at 70 to 600 amperes, 250 volts d-c or 600 volts a-c, two-pole, and 70 to 600 amperes, 600 volts a-c, three-pole. The breakers

Table II. Weight and Size Data

Connection	Weight (Pounds)	*Over-all Size		
		Width	Length	Depth
Front	53	8½	22	5½
Rear	62	8½	22	**11½

* Operating handle not included.
** Rear-connected terminals included.

2. For all numbered references, see list at end of paper.

as shown are for rear connection only. By adding a gas by-pass at the top front end of the cover, the breaker can be used for front connection. The gas by-pass assists the venting of the gas around the terminals. The same molded main base and cover are used for both the two- and three-pole breakers.

Since size was a very important factor in the development of this breaker, table II is given, listing the over-all size and weights of both the front- and rear-connected breaker units.

Final Test Results

Figure 6 illustrates the performance of the final breaker opening a short circuit at 36,000 amperes, 600 volts, 60 cycles, 3 phase. This particular breaker satisfactorily opened one open and CO short circuit at 20,000 amperes, one open and CO at 25,000 amperes, one open and CO at 26,000 amperes, and two open and CO short circuits at 36,000 amperes. The contacts and steel plates were burned but not excessively.

A similar breaker was tested to determine the effect of severe short circuits on the contact drop. Table I gives the short-circuit and contact-drop data. These data indicate that the contacts were still in excellent shape after six short circuits at 20,000 amperes. The increase in contact drop after the two 32,000 ampere short circuits is not enough to cause overheating or to affect the thermal trip calibrations.

Conclusion

The circuit breaker, as finally developed, is of a size which enables a compact and efficient switchboard construction, has a considerable safety margin over the 20,000-ampere rupturing capacity, and permits interchangeability of a large number of detail parts with the circuit breaker of the same normal rating but of 10,000 ampere rupturing capacity.

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5. Extinction of A-C Arcs in Turbulent Gases, T. E. Browne, Jr. Presented at the winter convention of the AIEE, New York, N. Y., January 25–29, 1932.

Line-Type Lightning Arrester Performance Data

THIS REPORT presents characteristics of line-type arresters rated 20 to 73 kv, and is a continuation of the previous subcommittee report on "Distribution Lightning Arrester Performance Data" published in the AIEE Transactions, volume 56, 1937, pages 576–7.

Data have been presented relating to the impulse characteristics of insulation both as used on lines and in stations. Data on the rates of voltage rise and current magnitude to be encountered by protective devices in the field are being accumulated rather slowly. In order to have a basis for comparing arrester characteristics, a standard test was set up which indicates the arrester protective characteristic which falls in the range of service conditions. While the test was empirically set up, the characteristics obtained can be compared with the insulation to show the margin of protection afforded.

The present standard requires an applied impulse voltage rising at the rate of 100 kv per microsecond per 11.5 kv of rating in these voltage classes. In effect this results in an impulse sparkover of the arrester series gap in about 0.4 microsecond after the impulse voltage begins to rise. After the arrester begins to discharge the impulse current should rise to 1,500 amperes in ten microseconds and fall to half value in ten more microseconds. This current results in a voltage drop or impedance drop across the characteristic element of the arrester. As the impedance drop varies somewhat with current, characteristics also are presented for currents of 3,000 amperes and 5,000 amperes.

The lightning-arrester manufacturers have furnished the data from which the average characteristic of available arresters are plotted and tabulated. Tolerances are given to include the expected

Table I. Line-Type Arrester Characteristics (20–73 Kv)

Arrester Rating (Kv)*		Gap Breakdown (Crest Kv)	Impedance Voltage; Crest Kv When Discharging Currents of 1500 Amperes	3000 Amperes	5000 Amperes
20	Max.	97	83	90	94
	Ave.	75	69	75	78
	Min.	52	55	60	63
25	Max.	118	104	112	118
	Ave.	95	87	94	98
	Min.	64	69	75	79
30	Max.	139	124	134	142
	Ave.	112	104	112	117
	Min.	78	83	89	94
37	Max.	169	155	168	176
	Ave.	135	129	140	146
	Min.	98	103	112	117
40	Max.	180	168	182	190
	Ave.	147	140	151	158
	Min.	104	112	121	127
50	Max.	225	210	228	238
	Ave.	180	175	188	198
	Min.	131	140	150	159
60	Max.	267	252	274	286
	Ave.	217	210	226	238
	Min.	157	168	182	190
73	Max.	323	309	333	348
	Ave.	265	258	278	290
	Min.	195	206	222	232

Notes: Gap breakdown taken on rate of voltage rise of 100 kv per microsecond per 11.5 kv of rating. All test currents 10/20 wave. The 60-cycle sparkover potential of all arresters shown in this tabulation will not be less than 150 per cent of arrester rating.

* These ratings are maximum permissible line-to-ground root-mean-square voltages.

Paper number 38-56, prepared by the lightning arrester subcommittee of the AIEE committee on protective devices, recommended by the AIEE committee on protective devices, and presented at the AIEE summer convention, Washington, D. C., June 20–24, 1938. Manuscript submitted March 25, 1938; made available for preprinting May 9, 1938.

Personnel of AIEE lightning arrester subcommittee: J. R. North, *chairman*; H. W. Collins, J. M. Flanigen, I. W. Gross, Herman Halperin, K. B. McEachron, J. R. McFarlin, A. M. Opsahl, A. H. Schirmer, H. K. Sels, L. G. Smith, H. R. Stewart, J. J. Torok, and H. L. Rorden.

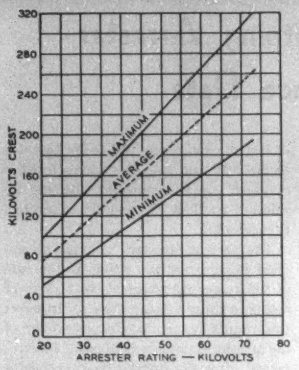


Figure 1. Impulse spark-over voltages, line-type arrester

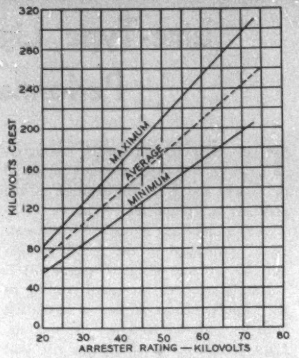


Figure 2. Impedance drop at 1,500 amperes, line-type arresters

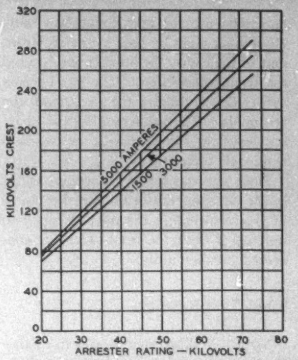
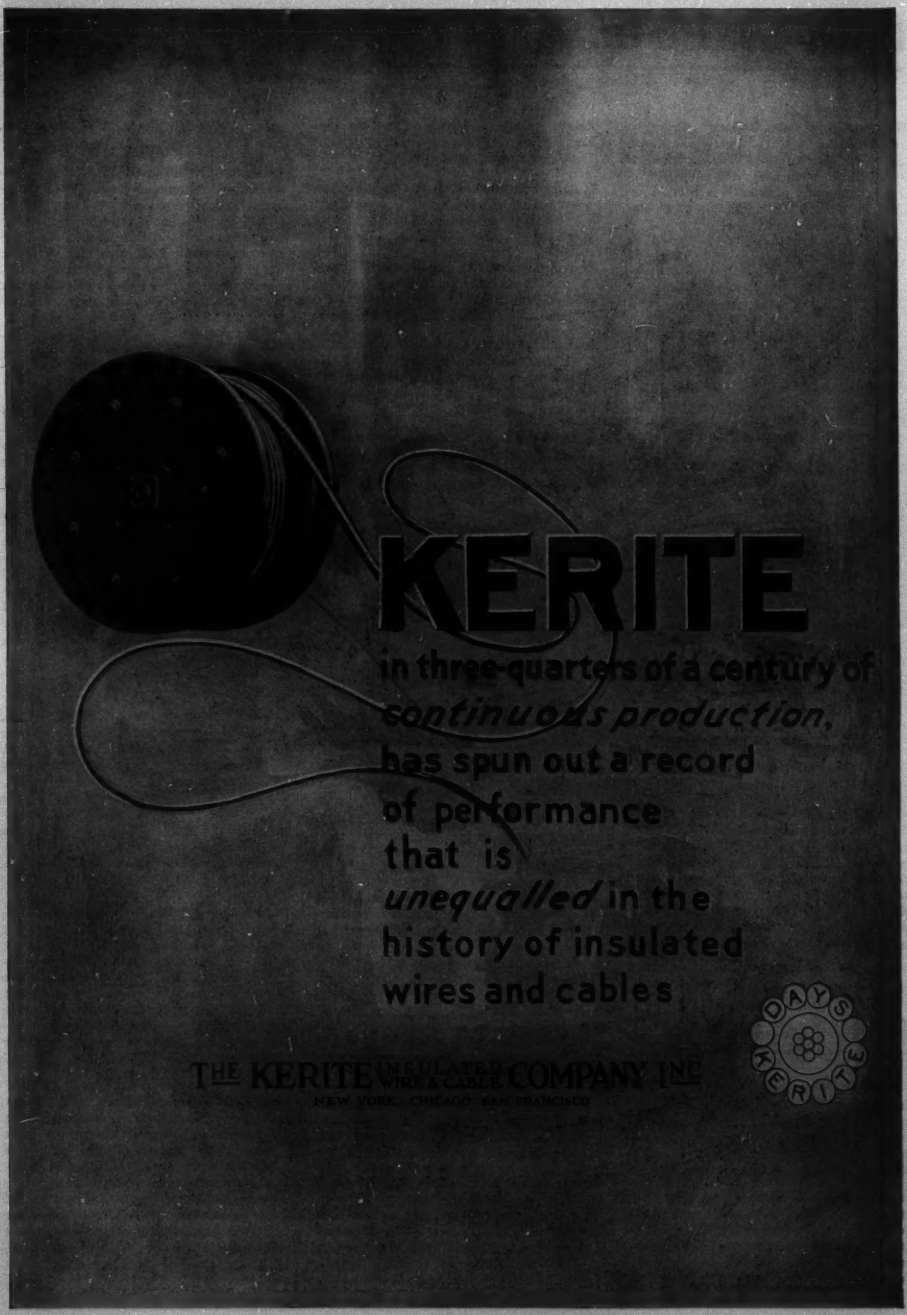


Figure 3. Average impedance drop, 1,500, 3,000, and 5,000 amperes, line-type arresters

variation from the average for the industry.

The over-all characteristic of the lightning arrester is usually given in the typical volt-time curve under specified conditions. The pertinent voltage magnitudes only are given here in order to simplify the data. By a comparison of the typical volt-time arrester characteristic with the volt-time characteristic of the insulation to be protected, a logical evaluation of the protection can be made.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Industrial Notes

Manufacturers' Sales Reports. Orders received by the General Electric Co. during the third quarter of 1938 amounted to $60,533,135, compared with $88,010,937 during the same quarter last year, a decrease of 31%. For the first nine months this year orders received amounted to $188,756,958, a decrease of 38% from the $305,276,556 received during the same period a year ago. Sales billed for the first nine months of 1938 reached $192,501,173, as against $260,773,533 during the corresponding period of 1937, a decrease of 26%.

Orders booked by the Allis-Chalmers Mfg. Co. for the third quarter this year amounted to $14,195,522 and sales billed were $19,961,455. For the similar period a year ago, the figures were respectively $26,325,076 and $24,209,497. Billings for the first nine months this year were $54,527,818, a decline of 31% as compared to the first three quarters of last year. Unfilled orders on September 30 amounted to $10,796,269, compared with $25,233,936 on the like 1937 date.

Gould Battery Acquires USL Division. Facilities formerly devoted to the manufacture of batteries for railroad, industrial and utility service by the USL Battery Corporation are being utilized for automobile battery manufacture and the company's industrial battery division has been discontinued. The Gould Storage Battery Corp., Depew, N. Y., has acquired the USL power battery department and will continue for USL customers complete inspection and replacement service covering USL industrial batteries now in service.

Allegheny-Ludlum Steel Appointment.—William P. Langworthy has been appointed director of the electrical materials division of the Allegheny-Ludlum Steel Corp. He was formerly president of the Lamination Stamping Co., Hartford, Conn., first and largest specialists in the fabrication of electrical steels. In 1930 the company was merged with the Allegheny Steel Co., with Mr. Langworthy becoming manager of the fabrication division, a position he has held up to the time of his present appointment.

Trade Literature

Transformers.—Bulletin 108, 32 pp. Describes and illustrates various types of current and potential transformers; prices are included. R. E. Uptegraff Mfg. Co., 300 North Lexington Ave., Pittsburgh, Pa.

Fuseswitches.—Bulletin 500-A, 32 pp. Describes housed and open type fuseswitches, cutouts, disconnecting switches, universal and secondary fuse links and accessories, for primary and secondary power distribution systems. Price list is included. W. N. Matthews Corp., St. Louis, Mo.

Relays.—Bulletin, 16 pp. Describes various types of relays and associate equipment. The Autocall Co., Shelby, O.

Magnetic Clutches.—Folder 112. Describes magnetic clutches, magnetic clutch-brake combinations and magnetic brakes. Stearns Magnetic Mfg. Co., Milwaukee, Wis.

Resistors.—Bulletins, in loose-leaf binder. Describe practically all types of resistors and resistance devices. Clarostat Mfg. Co., Inc., 285 N. Sixth St., Brooklyn, N. Y.

Solenoid Valves.—Bulletin, 10 sections. Describes solenoid operated valves for automatic and remote control of air, gas, steam and liquids. Automatic Switch Co., 154 Grand St., New York City.

Laminated Plastic.—Catalog, 48 pp. Describes "Dilecto," a laminated phenolic material, applicable to electrical insulating and other purposes. Continental-Diamond Fibre Co., Newark, Del.

Welding Accessories.—Cat. Sec. 26-620, 8 pp. Describes arc welding equipment and supplies, including helmets, lenses, electrode holders, miscellaneous accessories and welding publications. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Adjustable Speed Control.—Bulletin 1151-B, 8 pp. Describes the Rossman system of controlling the speed of a-c machines over a wide range, at unusually high efficiencies. Units in size from 165 to 2500 horsepower have been built and are in operation. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Electronic Voltmeter.—Bulletin 2, 4 pp. Describes a new sensitive electronic voltmeter, with frequency range of 10 to 100,000 cycles; voltage range .001 to 100 volts r.m.s. in five decade ranges. Ballantine Laboratories, Inc., Boonton, N. J.

Explosion-Proof Motors.—Bulletin 1225, 4 pp. Describes a new line of explosion-proof, ball-bearing motors, approved for class I group D hazardous locations. Double-end ventilation assures positive cooling from both ends of the motors, eliminating hot spots. Fairbanks, Morse & Co., 600 S. Michigan St., Chicago, Ill.

Wiring System.—Catalog 386, 36 pp. Describes Universal type "Trol-E-Duct," a flexible and convenient wiring method providing movable outlets for industrial plants and commercial buildings. Installation views and construction details are pictured. Bull Dog Electric Products Co., 7610 Jos. Campau Ave., Detroit, Mich.

Safety Switch Stick.—Bulletin 224, 4 pp. Describes a new safety switch stick with spiral hook that provides safe and positive control of any device being operated. The hook is twisted through the pull ring of a switch blade, cutout or fuse and grips the device against slippage. Schweitzer & Conrad, Inc., Chicago, Ill.

Portable Instruments.—Cat. 123-a, 4 pp. Describes two lines of portable instruments for general testing purposes and for use as secondary standards. Includes d-c ammeters, voltmeters, milli-voltmeters and milli-ammeters of all ranges, as well as a-c instruments of the same size and style of case. Roller-Smith Co., 233 Broadway, New York City.

Telemetering.—Bulletin 515, 24 pp. Describes the Metameter system of telemetering. Includes detailed information on telemetering instrument readings. Illustrates various models available for remote measurement and automotic control of pressure, vacuum, liquid level, temperature, flow, voltage, current, load and totalized power load. The Bristol Co., Waterbury, Conn.

Voltage Regulator.—Bulletin 1194, 8 pp. Describes type J rocking contact rheostatic generator voltage regulator for control of large synchronous machines. The regulator is specially suited for use with a-c generators, synchronous condensers, generator line charging and protection against excessive over-voltage on hydroelectric units due to sudden loss of load. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Electrical Steel Sheets.—Booklet, 32 pp., "ARMCO" Electrical Sheet Steel. Describes various types of electrical sheet steel and the development of special grades to meet different demands of the electrical industry. Illustrations include equipment used in production and testing of sheets and their applications. Charts and statistical tables presenting core losses and other data for the guidance of users are included. The American Rolling Mill Co., Middletown, O.

Pyrometers.—Bulletin B1138, 2 pp. Describes the Thwing indicating radiation pyrometer for measuring temperatures in metallurgical and ceramic operations, in furnaces, coke ovens, boiler fire pits, etc. No part of the instrument is inserted in the heat so that there is no high limit to temperatures that may be measured. Made in portable, laboratory portable and wall types. Thwing-Albert Instrument Co., 3339 Lancaster Ave., Philadelphia, Pa.

Current Transformers.—Bulletin GEA-2895, 4 pp. Describes type KF-326 current transformers designed for outdoor service on 69,000-volt circuits. Available in primary current ratings up to 3000 amperes and can be furnished with single or double secondary windings. High accuracy over both the normal current range and under overcurrent conditions makes it suitable for either metering or relay applications. General Electric Co., Schenectady, N. Y.

Insulation Tester.—Bulletin 112, 6 pp. Describes an insulation compactness tester for evaluating the compactness of layer structure and density of filler spaces of paper insulated power transmission cable. This instrument is referred to in the article "Mechanical Uniformity of Paper-Insulated Cable" published in the March 1938 issue of ELECTRICAL ENGINEERING. A number of refinements have since been added to the device for greater ease of operation. Central Scientific Co., 1700 Irving Park Blvd., Chicago, Ill.

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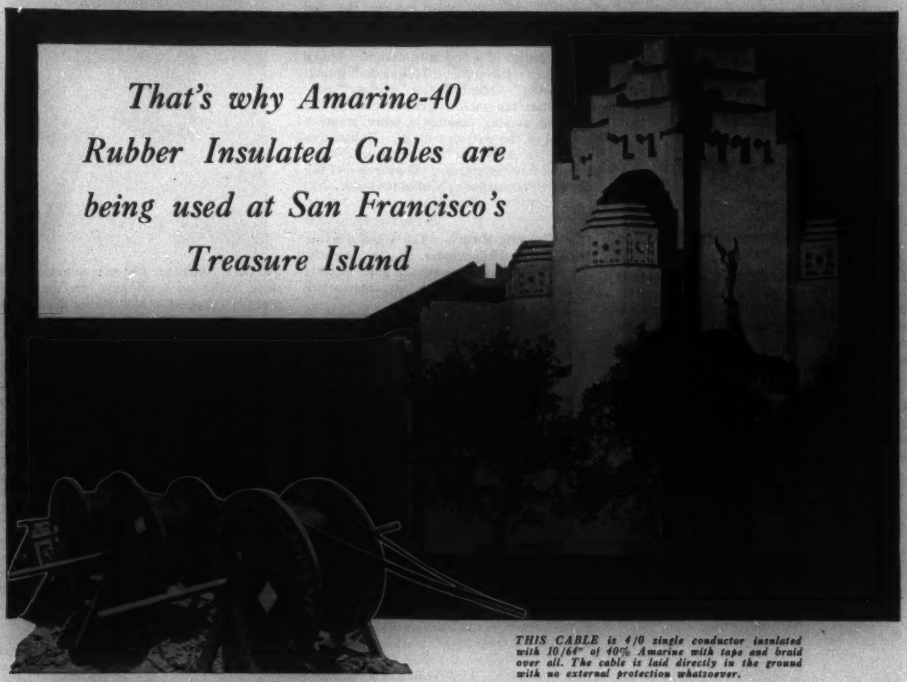

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TREASURE ISLAND, the site of the GOLDEN GATE International Exposition is "made land." This beautiful spot was literally pumped up from the bottom of the sea. The soil which composes Treasure Island contains quantities of salt and other deleterious substances. Where could one find a spot that offered tougher conditions for cables to resist?

The Engineers of the Golden Gate International Exposition thoroughly investigated rubber insulating compounds for use in their buried feeders which must supply the various buildings and equipment on Treasure Island. The result was that they specified Amarine 40 or its equivalent and purchased a large quantity for this service.

Amarine-40 is an insulating compound designed especially for cables operating under water without protection of lead or other water-proof coverings. Its outstanding characteristics are low water absorption, low specific inductive capacity, good aging qualities and high insulation resistance. Amarine compound is still serving in some of the earliest installations of non-leaded submarine cable. Its excellent properties were the reasons for the Exposition Engineers' decision to use Amarine-40 for this severe service.

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New Products

Strain Clamp. To accommodate the middle range of conductor sizes, those ranging from $^3/_{16}$ to $^7/_{16}$ inch, the Ohio Brass Co., Mansfield, Ohio has brought out an intermediate

universal strain clamp. Having a reversible keeper piece it will take any standard conductors from 8A to 2A Copperweld, from No. 4 to 3/0 solid copper, from No. 5 to 2/0 stranded copper, and from No. 6 to No. 2 A.C.S.R. The rated ultimate strength of the clamp is 10,000 pounds.

Oil Circuit Breaker. The Roller-Smith Co., 12 Park Place, New York City, has added to its line a "Turblator" oil circuit breaker, manhole, submersible type, for use in under-

ground distribution systems; it may also be used outdoors. The automatic features may consist of 1-, 2- or 3-trip coils and bushing type current transformers. Shunt trip coil, auxiliary switches and other attachments are available when specified. Class 50-M; 200, 400 and 600 amperes; 7500 volts; 50,000-kva interrupting capacity.

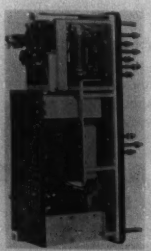
Corrosion-Resistant Conduit. A new development in protecting steel conduit has recently been announced by Walker Brothers, Conshohocken, Pa. By a process known as "Walkerizing," a uniform coating of zinc is fused into the inside and outside walls of the steel tube. Over this is applied a second coating containing a new, inert substance, which offers strong resistance to acids, alkalis and salt water. According to the manufacturer the new conduit may be used to advantage not only in locations where chemical conditions create serious corrosion problems, but to assure longer service in all types of installations.

Voltage Regulator. A new, panel-type "Voltrol" has been designed by the Acme Electric & Mfg. Co., Cuba, N. Y. More compact than the older models, the new Voltrol permits stepless adjustment of a-c voltage from 0 to 135 volts. Basically, the unit consists of a specially designed heavy duty auto transformer. It has non-burning, non-fusing, self-lubricating rheostat contacts that tap each individual turn of the winding making possible a more accurate control of the output voltage. Exhaustive testing to determine its operating characteristics have established the accuracy of the device to adjustments within 0.40 volt.

High-Capacity Switch. The I-T-E Circuit Breaker Co., Philadelphia, Pa., has recently completed a hand-operated, 3-pole, 10,000-ampere disconnect switch, so constructed

that all three poles are opened or closed in unison, thus constituting, in effect, the opening or closing of a 30,000-ampere, single-pole switch. Attention is called by the manufacturer to the ease with which this huge switch is manually operated, effected through the incorporation of the patented "Klamp-Tite" feature, as compared to the effort required to operate a conventional type knife switch of a fraction of its capacity.

Relay.—A new high speed, percentage differential relay, type HDD, for transformer protection is announced by the General Electric Co. It effects a combination of harmonic and percentage restraint principles in operation. Two types of the HDD relay are available: the HDD11A for two-winding transformer protection, and the HDD11B for three-winding transformers. Both are mounted in standard universal cases, $5^1/_2$ by 16 inches, suitable for flat surface or semi-flush mounting. They are single-phase units, and three are required for the protection of a three-phase transformer bank.

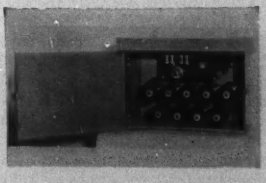


Clamp Connector. A connector especially adapted for taking copper and galvanized taps from A.C.S.R. over the armor rods has been introduced by the Burndy Engineering Co., Inc., New York City. The connector consists of three clamping elements held in place by two bolts, so arranged that the

five parts constitute virtually a single piece; thus, under no conditions can individual parts be dropped or lost during installation or in transit. The design of the armor rod clamp permits the aluminum armor rods to bear against a galvanized surface, and the copper tap to bear against a copper surface. A constant spring pressure is maintained between conductors, thereby providing a permanently secure connection.

Paint for Creosoted Timber.—The Reilly Tar and Chemical Corp., Indianapolis, Ind., has developed a paint for creosoted utility poles, structural timbers, etc. The new product, known as "Creocote," forms an effective seal through which neither pitch nor creosote will penetrate, and provides a dry, hard bright finish which is highly resistant to abrasion and wear and is impervious to oils and dilute acids.

Rectox Rectifier.—To counteract and practically eliminate galvanic action or electrolysis of underground pipe lines, cables, etc., a copper-oxide rectox rectifier



for cathodic protection has been developed by the Westinghouse Electric & Mfg. Co. These rectifiers have a rating range from 3 to 50 volts, 1 to 125 amperes d-c output. They consist of the necessary rectox units for the desired rating, together with a two-winding transformer, disconnect switch, and terminal board, all mounted on sheet steel ventilated cabinet designed in some cases for outdoor use and in others for indoor use. They have no rotating parts and operate entirely without noise. An important characteristic is that operation causes no radio interference.

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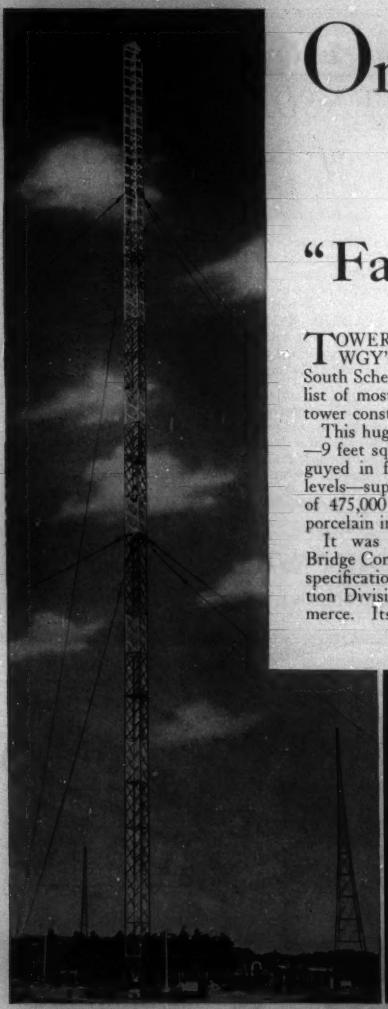

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• • •

W. J. Purcell, Chief Engr., Station WGY.

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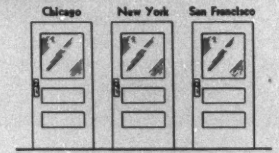

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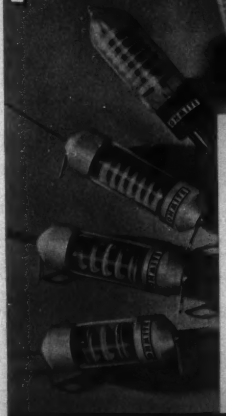

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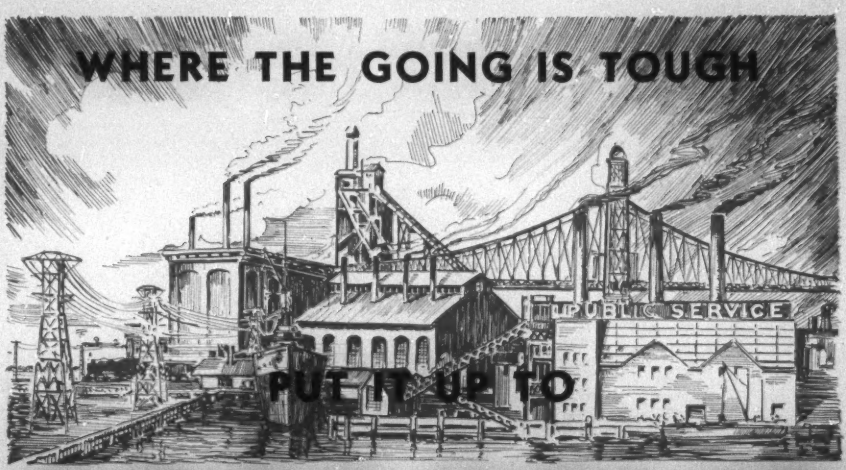

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